VANCOUVER OXIDANTS STUDY:

CONTROL TECHNOLOGY OPTIONS AND COSTS FOR VOLATILE ORGANIC COMPOUND EMISSIONS FROM GASOLINE MARKETING

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SUMMARY

I. INTRODUCTION

A series of studies were recently completed on emissions of contaminants to the atmosphere in the Lower Mainland of British Columbia through the collective efforts of the Greater Vancouver Regional District, the B.C. Ministry of Environment and Environment Canada. As part of this program, a study was completed which prepared a computerized inventory of sources and emissions of volatile organic compounds for the gasoline marketing network in the study area (Edwards, 1988).

This study was concerned with VOC emissions from gasoline marketing and included as its main tasks:

- characterization of the aspects of each source having an impact on the effectiveness and cost of VOC emission control systems;
- identification and discussion of VOC emission control systems;
- development of capital and operating costs as well as cost effectiveness for total VOC removed for selected emission sources;
- assessment of the impact of the implementation of possible control strategies on VOC emissions from the gasoline marketing network.

II. VOC EMISSIONS FROM GASOLINE MARKETING

A. Handling of Gasoline in the Marketing Network

Figure S-1 illustrates schematically the gasoline marketing network in the study area. Gasoline stored in tanks leaves the refineries by pipe, truck, barge and drums. Gasoline is distributed from bulk terminals by tank trucks to service stations, bulk plants and bulk end users. Gasoline from bulk plants may be shipped via truck to service stations and bulk end users. Bulk end users store and redistribute gasoline to service their own vehicles. Gasoline is imported into the study area on occasion and is also exported out of the study area.

B. Description of Sources of VOC Emissions

1. Storage of Gasoline

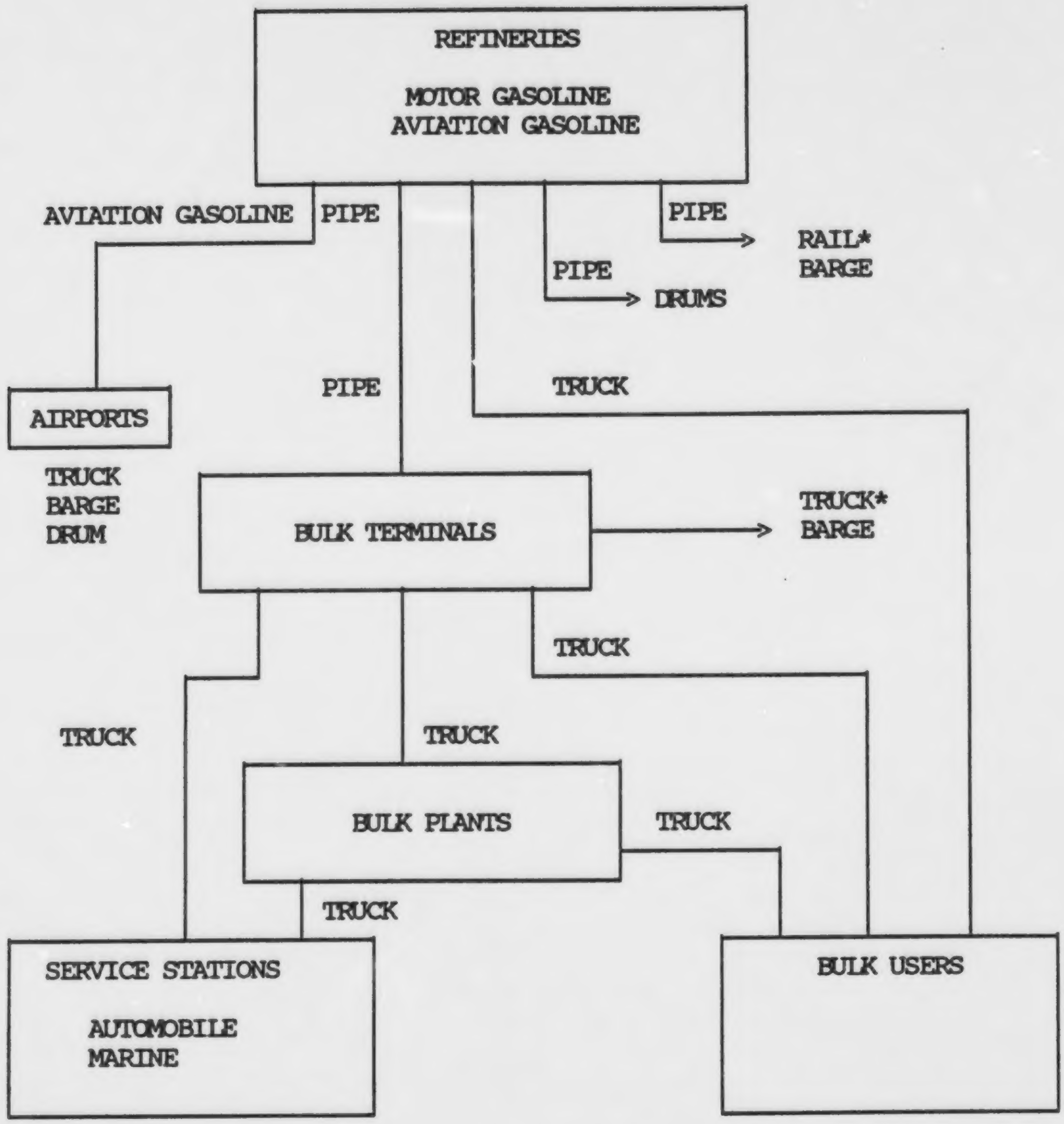
Emissions arise from the storage of gasoline in above-ground and underground tanks. Changes in ambient temperature and pressure give rise to breathing losses in fixed roof tanks. Filling and emptying fixed roof tanks results in working losses. External and internal floating roof tanks have decks which float on the gasoline thereby greatly reducing losses during filling and emptying operations. However, emissions do arise from the evaporation of gasoline from the annular space between the floating deck and the wall, from gasoline clinging to wall when product is taken from the tank and from evaporation through deck fittings. The external cover on top of internal floating roof tanks greatly reduces these standing and withdrawal losses, making them the lowest emitting tank type per unit of gasoline throughput. For underground tanks, emissions arise predominantly during filling operations because diurnal temperature change is minimal.

2. Bulk Transfer of Gasoline

The majority of VOC emissions occur during fuel loading operations. Top or bottom submerged filling greatly reduces emissions compared to top splash loading methods.

3. Motor Vehicle Refueling

Refueling generates emissions by displacing the vapours from the vehicle fuel tank and by spillage during the refueling process. Prefill and post-fill nozzle drip, spit-back and overflow contribute to spillage.


REFINERIES
MOTOR GASOLINE
AVIATION GASOLINE
AVIATION GASOLINE
PIPE
PIPE
PIPE
RAIL*
BARGE
PIPE
DRUMS
AIRPORTS
PIPE
TRUCK
TRUCK
BARGE
DRUM
BULK TERMINALS
TRUCK*
BARGE
TRUCK
TRUCK
TRUCK
BULK PLANTS
TRUCK
TRUCK
SERVICE STATIONS
AUTOMOBILE
MARINE
BULK USERS

* Out of study area

FIGURE S-1 GASOLINE MARKETING NETWORK

C. Fuel Quantities and Emissions for the Various Sources

There are over 800 sources of VOCs in the gasoline marketing network in the study area. The 11 largest sources account for 32% of the total emissions. Some 600 automobile service stations emit 46% of the total emissions. Table S-1 lists the VOC emissions for major source types.

D. Sources Selected for Study of Control Options

The source tpes having the top four annual emission levels, excluding bulk users, which are individually small, were selected for study of control options. These sources emitted 81.4% of the annual total of 6516.6 tonnes in 1985 with individual contributions as follows:

	Annual Emission (t)	Percent of Total (%)
Automobile service stations	3023.0	46.4
Bulk terminal truck loading	1226.6	18.8
Barge and ship loading	599.8	9.2
Fixed roof tanks	453.8	7.0
	5303.2	81.4

TABLE S-1 VOC EMISSION FOR MAJOR SOURCE TYPES

SOURCE TYPE	ANNUAL FUEL THROUGHPUT ($10^3 m^3$)	PERCENT OF TOTAL FUEL (%)	ANNUAL EMISSION (t)	PERCENT OF TOTAL EMISSIONS (%)
Tanks				
External floating roof	1,472.4	14.1	101.2	1.6
Internal floating roof	3,117.5	29.8	70.6	1.1
Fixed roof	524.3	5.0	453.8	7.0
Underground (excluding service stations)	22.9	0.2	24.1	0.4
Subtotal	5,137.1	49.1	649.7	10.1
Loading Operations				
Truck	2,050.7	19.6	1,226.6	18.8
Railcar	68.4	0.7	41.5	0.6
Barge and ship	1,357.5	13.0	599.8	9.2
Subtotal	3,476.6	33.2	1,867.9	28.6
Service Stations				
Automobile	1,395.2	13.3	3,023.0	46.4
Aircraft	0.7	0.0	1.3	0.02
Marine Vessels	4.3	0.0	9.2	0.1
Subtotal	1,400.2	13.4	3,033.5	46.5
Bulk Users (dedicated service stations)	450.0	4.3	965.5	14.8
Total	10,463.9	100	6,516.6	100

III. SPECIFICATIONS FOR SOURCE CONTROL SYSTEMS

A. Characteristics of Selected Sources

Four fixed roof tanks located at bulk terminals accounted for 78.1% of the emissions from fixed roof tanks. They range in capacity from 2400 m^3 to 4300m^3. Throughputs range from 36,800 to 218,300 m^3/yr per tank. Forty-two fixed roof tanks located at 15 bulk plants have capacities of less than 136 m^3 and are typically 60 m^3. Throughput for these tanks ranges from 220 to 4100 m^3/yr per tank.

In 1985, over 90% of the total gasoline transferred was handled by truck at the four bulk terminals and by ship or barge at the four refineries. VOC emissions arising from gasoline transfer at each of the bulk terminals ranged from 215 t/yr to 390 t/yr. VOC emissions arising from gasoline transfer at the refineries ranged from 79 t/yr to 223 t/yr. Throughput at the refineries ranged from 170,000 m^3/yr to 480,000 m^3/yr, while throughputs at the bulk terminals ranged from 380,000 m^3/yr to 710,000 m^3/yr.

Some 600 service stations are located in the study area. Stations varied in throughputs from nearly zero to 7000 m^3 of gasoline sales/yr. Stations had 1 to 4 islands with 1 to 20 nozzles.

IV. EVALUATION OF EMISSION CONTROL SYSTEMS

A. Gasoline Storage Tanks

Emissions from fixed roof tanks with capacities of 150 m^3 or more can be controlled by adding floating decks. Decks can be constructed from materials such as steel, aluminum or polyurethane. Primary and even secondary seals can be used to seal the annular space between the deck and the tank wall. The deck type and seal tightness affect the emissions reduction achieved, which typically is in excess of 90%.

Emissions from fixed roof tanks with capacities less than 150 m^3 can be controlled by vapour balancing during filling operations. The integrity of the vapour balance system is improved by preventing leaks and overfills, and by properly maintaining equipment. Reduction efficiencies of 95% can be achieved.

Emissions from external floating roof tanks can be controlled by installing secondary seals. Emissions reductions in excess of 50 - 60% can be expected, depending on several factors including seal type, throughput, wind speed and temperature.

B. Bulk Transfer of Gasoline

Emissions arising from loading operations at bulk terminals can be controlled by installing vapour processing equipment. The vapours can be destroyed by thermal oxidation or they can be recovered by refrigeration or carbon adsorption-absorption processes. Table S-2 compares the three processes.

C. Service Stations

Vapour balancing techniques can be applied at service stations to control emissions arising during gasoline delivery and vehicle refueling operations. Vapours displaced from vehicle fuel tanks can be returned to the underground storage tanks. Vapours displaced from underground storage tanks can be returned via the delivery truck to control vapour processing facilities located at bulk terminals. Vapour capture efficiencies in excess of 95% are possible for vapour balance systems during fuel deliveries. In-use vapour capture efficiencies of 48% to 92+% have bene reported for vapour balancing during vehicle refueling. These efficiencies are strongly affected by the level of equipment maintenance. Consequently, frequent inspections should be considered by the local air regulatory authority.

TABLE S-2 COMPARISON OF VAPOUR CONTROL SYSTEMS

	REFRIGERATION	CARBON ADSORPTION-ABSORPTION	THERMAL OXIDATION
Capital Cost	Highest	Middle	Lowest
Energy Costs	Higher	Lower	Higher
Product Recovery	Yes	Yes	No
Fire/Explosion Hazard	Very low	Moderate	Moderate
Calculation of Recovery/ Destruction Efficiency	Measured directly	Estimated	Estimated
Operation	Requires daily defrosting	Can shut down during operation lulls	Can shut down during operating lulls
Discharge emissions (mg/VOC/litre of throughput)	- 35	< 35	< 35

D. RVP Reduction

Reducing gasoline RVP is another means available to control VOC emissions from the marketing network. RVP reduction will also reduce evaporative emissions from the motor vehicles themselves.

The simplest and most direct way of reducing RVP is to reduce the amount of butanes blended into gasoline. Because butane is a high octane component, other high octane products would have to be substituted. MTBE or other ethers could be added to boost the octane without increasing the RVP.

Refinery operations and processes could be modified, added or expanded to reduce gasoline volatility. For example, reformer catalyst could be imporved, reformer operating pressure could be lowered, alkylation, catalytic polymerization, dimerization and MTBE capacity could be added, among other options.

Reducing RVP would have little impact on hot soak losses, but would have a significant impact on diurnal losses. Driveability as measured by cold start and warm-up tests would not be significantly impacted by RVP reductions to 48 kPa.

E. Control of Toxic Emissions

Evaporative and exhaust space benzene emissions increase with increasing benzene content in the gasoline and with increasing gasoline aromatic content. Typical benzene contents of gasoline range from 1 - 3%, while aromatics can account for up to 40% or more.

V. ESTIMATED VOC REDUCTIONS BY IMPLEMENTATION OF CONTROLS

Installation of floating decks in the four fixed roof tanks located at bulk terminals could reduce VOC emissions from these sources by 98% from 354 tonnes to 7 tonnes.

Vapour control at bulk terminals for truck loading operations could reduce the associated VOC emissons by 90% from 1166 tonnes to 115 tonnes. This assumes a vapour processor discharge rate of 35 mg of VOC per litre of gasoline transferred (35 mg/L) and a 4% fugitive emission rate from the vapour collection system.

Vapour control could reduce emissions from marine terminals by 74% from 596 tonnes to 156 tonnes, assuming a 20% fugitive emission rate and a 35 mg/L vapour processor discharge rate.

Vapour balancing during gasoling deliveries at bulk plants could reduce emissions from these sources by 84% from 68 tonnes to 11 tonnes. The vapour balancing equipment used to control working losses was assumed to have a 5% fugitive loss.

Vapour balancing during gasoline deliveries at service stations could reduce emissions by 47% from 3023 tonnes to 1602 tonnes. Including vehicle refueling vapour balancing, emissions could be reduced by 82% from 3023 tonnes to 537 tonnes. These estimates assume a 5% fugitive emission loss and a 75% vehicle refueling capture efficiency.

Reducing RVP would reduce emissions not only from gasoline marketing sources but also from motor vehicle sources. Limiting RVP during the period May 1 to September 30 to 79, 72, 69 and 62 kPa could reduce emissions by 0.9, 3.1, 5.1 and 9.1%, respectively. These reductions are based on the current maximum RVP levels during the summer of 72 to 83 kPa.

VI. COST OF EMISSION CONTROL SYSTEMS

A discounted cash flow method was used to determine the present value of the capital and operating costs of control systems. This methodology was applied to determine the cost effectiveness of control options in terms of the present value of costs per tonne of VOC emission reduction.

Cost effectiveness was determined for the four source types listed in Table S-3 using a case study approach. Each case was selected to be representative of the sources present in the study area. Various cases other than those indicated in Table S-3 were also considered.

For each of the individual case studies, the cost effectiveness of applying the control option to all corresponding sources in the study area were determined. The control scenarios anlayzed in this way were:

- fixed roof tanks;
- truck loading terminals;
- terminals and service staiton deliveries;
- terminals and service station deliveries and vehicle refueling;
- a combination of all the above scenarios.

TABLE S-3 SUMMARY OF COST EFFECTIVENESS OF SOME OF THE CONTROL OPTIONS STUDIED

CASE		COST EFFECTIVENESS ($/tonne VOC reduction)
Fixed roof tank > 150 m^3		
- retrofit internal floating roof		-140
Truck loading with vapour control*		
- carbon adsorption/absorption		120
- refrigeration		230
- thermal oxidation		270
* Throughput 400,000 m^3/yr		
Bulk plants		
- vapour balancing of fixed roof tanks		190
Service stations		
- throughput (m^3/yr)	2,000	4,000
- nozzles	12	16
- vapour balancing during deliveries	310	30
- vapour balancing during deliveries and vehicle refueling	2,030	1,130

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. The major VOC source categories for the study area, accounting for over 90% of the total VOC emissions, were:

   - storage of gasoline in fixed roof tanks > 150 m^3;
   - loading of trucks at bulk terminals;
   - loading of ships and barges at marine terminals;
   - service stations (collectively);
   - bulk users (collectively).

2. The 1985 emissions inventory was:

Total VOC's	6516.6 tonnes
Benzene[1]	18.9 tonnes
Toluene[1]	7.8 tonnes
Xylene[1]	1.3 tonnes

3. Proven technology for the control of VOC emissions could be applied to the following source categories, which account for almost 70% of the total VOC emissions in the study area:

   - storage of gasoline in fixed roof tanks > 150 m^3 by retrofitting the fixed roof tanks to internal floating roof tanks;

   - loading of trucks at bulk terminals by installing vapour collection and recovery equipment;

   - service stations by vapour balancing during deliveries and vehicle refueling;

   - bulk plants by vapour balancing fixed roof tanks during deliveries.

   Reductions of 3895 tonnes, almost 60% of the total VOC emissions from gasoline marketing in the study area could be realized by applying this proven technology.

4. The cost effectiveness of applying the control technology ranged from -$ 110/tonne of VOC to $ 4,000/tonne of VOC.

---

[1] Based on speciation factors determined in this study.

5. The emission reduction and cost effectiveness of the various strategies are listed in order of cost effectiveness:

Fixed roof tanks	347.0 tonnes	$ -110/tonne
Truck terminals	1,051.2 tonnes	$ 80/tonne
Bulk plants	56.7 tonnes	$ 190/tonne
Service stations vapour balancing		
- during deliveries	1,420.8 tonnes	$ 340/tonne
- during vehicle refueling	1,056.6 tonnes	$ 4,000/tonne

6. The five scenarios evaluated are listed with cost effectiveness and combined emission reductions:

Scenario I	fixed roof tanks only	347.0 tonnes	$ -110/tonne
Scenario II	truck terminals only	1,051.2 tonnes	$ 80/tonne
Scenario III	Scenario II + service stations - delivery vapour balancing	2,446.2 tonnes	$ 170/tonne
Scenario IV	Scenario III + service stations - vehicle refueling vapour balancing	3,491.2 tonnes	$ 1,300/tonne
Scenario V	Scenario I + Scenario IV + bulk plants	3,894.9 tonnes	$ 1,200/tonne

7. Summertime gasoline volatility reductions would reduce emissions from gasoline marketing sources by less than 10% even when reduced to 62 kPa from levels of 72 - 86 kPa. This, of course, does not include reductions in emissions from motor vehicles that would result from using gasoline having a lower RVP. Literature reviewed in this study indicates that diurnal losses from vehicles is most sensitive to RVP reduction.

8. Emissions of aromatics can be reduced by the various control strategies as follows:

Fixed roof tanks	1.5 tonnes
Truck terminals (alone)	4.7 tonnes
Bulk plants	0.25 tonnes
Service stations vapour balancing	
- during deliveries	6.1 tonnes
- during vehicle refueling	4.6 tonnes

B. Recommendations

1. The speciation factors determined in this study are only an example for a typical "winter" gasoline vapour at about 12°C. More sampling and analysis is needed to determine the range of concentrations of the various species for all grades and brands of gasoline throughout the year and, in particular, "summer gasoline", and for emissions from the different types of sources that are present.

2. A detailed study is needed to determine the cost impacts of RVP reduction at refineries in Western Canada. A regional or, possibly, national perspective may be needed in this study to calculate costs of RVP reduction with confidence. This perspective is needed because of the national and international marketing of refinery products.

3. More information about the cost of retrofitting barges and ships for vapour balancing is needed before the cost effectiveness of vapour balancing at marine terminals can be estimated. The costs of the processing units and required piping are expected to be comparable to those for handling of vapours from truck loading.

4. More information about bulk users is required before any controls could be considered for this source. As a beginning, data should be obtained on the practises followed and the tankage present at major bulk users.

5. Industry with fixed roof tanks might wish to look at the economics of retrofitting the existing large fixed roof tanks to internal floating roofs.

6. The calculated cost effectiveness of VOC controls for sources in the gasoline marketing network should be compared to those for other sources of VOC emissions to establish optimal strategies for VOC reduction in the Lower Mainland. In the case of reduction of RVP, VOC emissions are reduced both in the gasoline marketing network and for the gasoline end-users, resulting in

reduction in VOC emissions significantly greater than for the gasoline marketing network alone.

7. If a decision is made to implement controls for sources in the gasoline network, then the controls discussed in this study should be applied to the following sources, in order:

   - fixed roof tanks > 150 m^3;

   - truck loading terminals;

   - bulk plants (vapour balance for fuel deliveries);

   - service stations - Stage I (vapour balance for fuel deliveries);

   - service stations - Stage II (vapour balance for vehicle refueling);

   - barges and ships.

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I. INTRODUCTION

A. Background

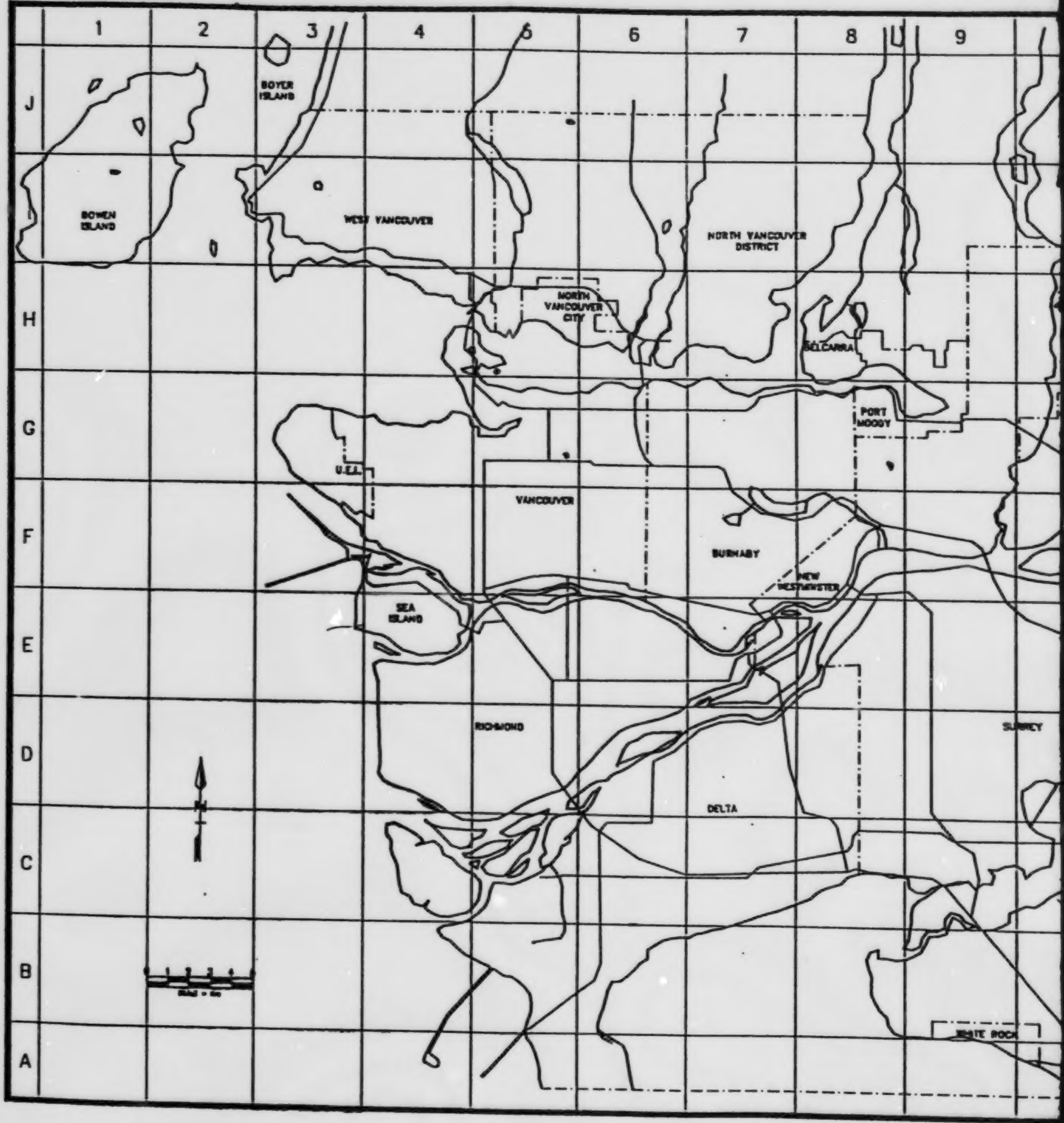
A series of studies were recently completed on emissions of contaminants to the atmosphere in the Lower Mainland (Figure I-1) of British Columbia through the collective efforts of the Greater Vancouver Regional District, the B.C. Ministry of Environment and Environment Canada. As part of this program, a study was completed which prepared a computerized inventory of sources and emissions of volatile organic compounds for the gasoline marketing network in the study area (Edwards and Levelton, 1988; Edwards, 1988).

The primary objective of the recently completed studies was the development of an inventory of VOC emissions for the base year 1985 from fuel storage and transfer operations associated with gasoline marketing. Emissions were originally to be determined for other fuels in addition to gasoline, such as diesel, jet A and jet B fuels. However, preliminary calculations indicated that gasoline contributes about 99% of the total VOC emitted from fuel marketing. For this reason, the study focused on emissions from marketing of gasoline only.

The emissions inventory prepared for gasoline marketing in the Lower Mainland included the following sources:

- fuel loading operations, including tank trucks, rail cars, ships, barges, aircraft, motor vehicles, small watercraft and marine vessels;
- fuel storage (tank breathing and working loss emissions) in fixed roof, external floating roof, internal floating roof and underground tanks.

Statistics were kept in the data base system on the fuel throughput and the physical dimensions and capacities of the sources in the study area. This information was used with the best currently available empirical relationships to calculate emissions on an individual basis for most cases. Emissions from bulk users that operate dedicated vehicle refueling stations for their own vehicles were calculated on an area basis since data on individual users was not available. The specific UTM (Universal Transverse Mercator) coordinates of all but the bulk user sources were included in the data base system, along with the number of the corresponding grid cell. With this information, emissions can be summarized on a grid cell basis or as point sources for input to a photochemical model.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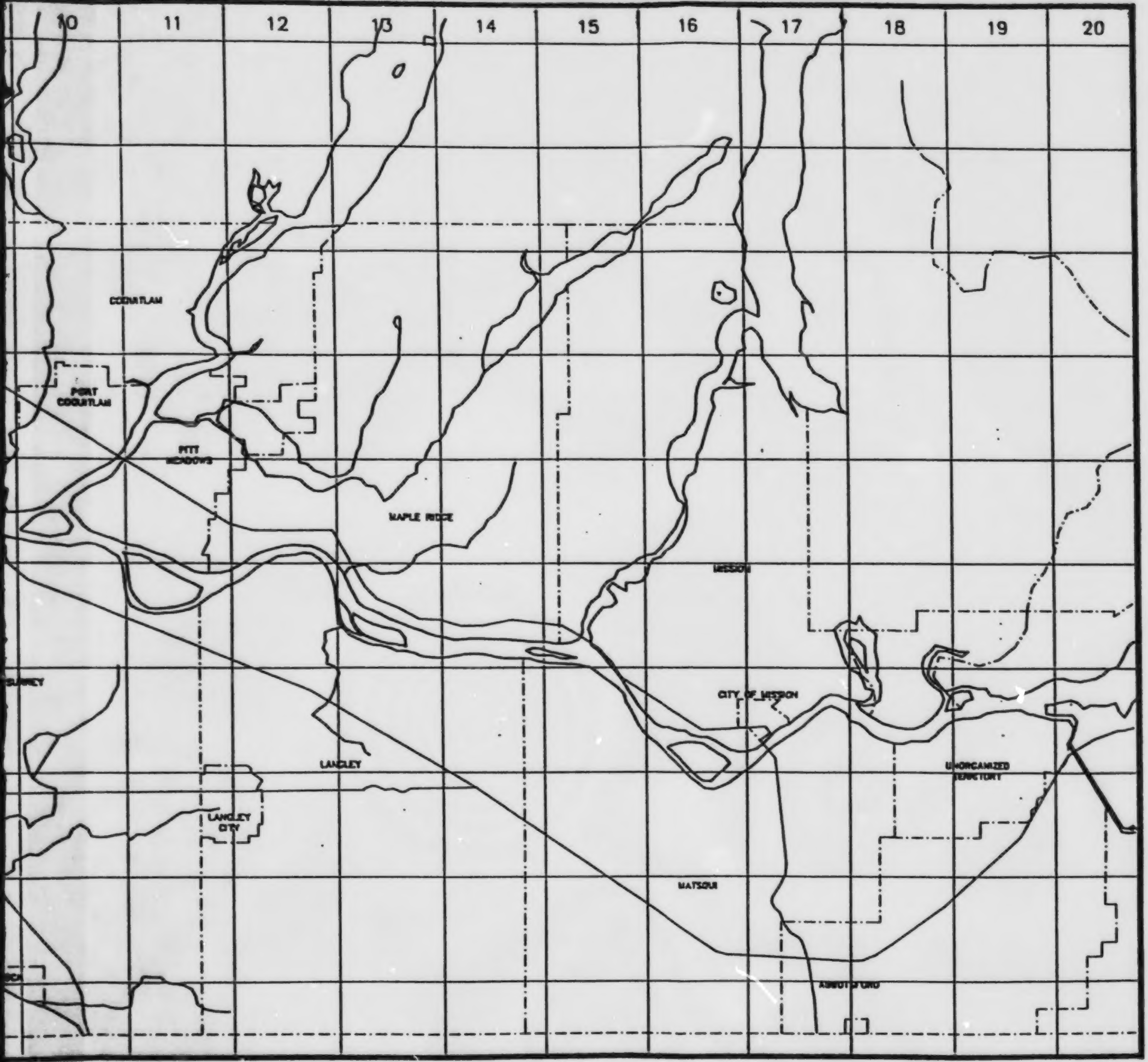
BOYER ISLAND
BOWEN ISLAND
WEST VANCOUVER
NORTH VANCOUVER DISTRICT
NORTH VANCOUVER CITY
BELCARRA
PORT MOODY
U.E.L.
VANCOUVER
BURNABY
NEW WESTMINSTER
SEA ISLAND
RICHMOND
SURREY
DELTA
WHITE ROCK
N

FIGURE I-1 LOWER MAINLAN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COQUITLAM
PORT COQUITLAM
PITT MEADOWS
MAPLE RIDGE
MISSION
SURREY
CITY OF MISSION
LANGLEY
LANGLEY CITY
UNORGANIZED TERRITORY
MATSQUI
ABBOTSFORD

AINLAND STUDY AREA WITH GRID SYSTEM

B. Scope of Work

This study includes as its main tasks:

- summarization of the emission inventory for the gasoline marketing network in the study area to obtain the data needed for determining the performance and cost impact of VOC control options for gasoline marketing sources;
- characterization of the aspects of each source having an impact on the effectiveness and cost of the control system;
- identification and discussion of emission control systems;
- development of capital and operating costs as well as cost effectiveness for total VOC removed for selected emission sources;
- assessment of the impact of the implementation of possible control strategies on VOC emissions from the gasoline marketing network.

II. VOC EMISSIONS FROM GASOLINE MARKETING

A. Handling of Gasoline in the Marketing Network

Figure II-1 illustrates schematically the gasoline marketing network in the study area.

1. At Refineries

Gasoline stored in tanks leaves the refineries in several ways to a number of destinations:

- via tank-to-shore pipeline to tankers for export out of the study area;
- via tank-to-shore or tank-to-rail pipelines to barges, coastal tankers and rail tank cars which service marine stations, and some bulk users in the study area;
- via dedicated pipeline to bulk terminals;
- via tank truck carrying aviation gasoline (not jet fuel) to local airports;
- via drums, principally carried on coastal barges and tankers, though also distributed in the study area to bulk users.

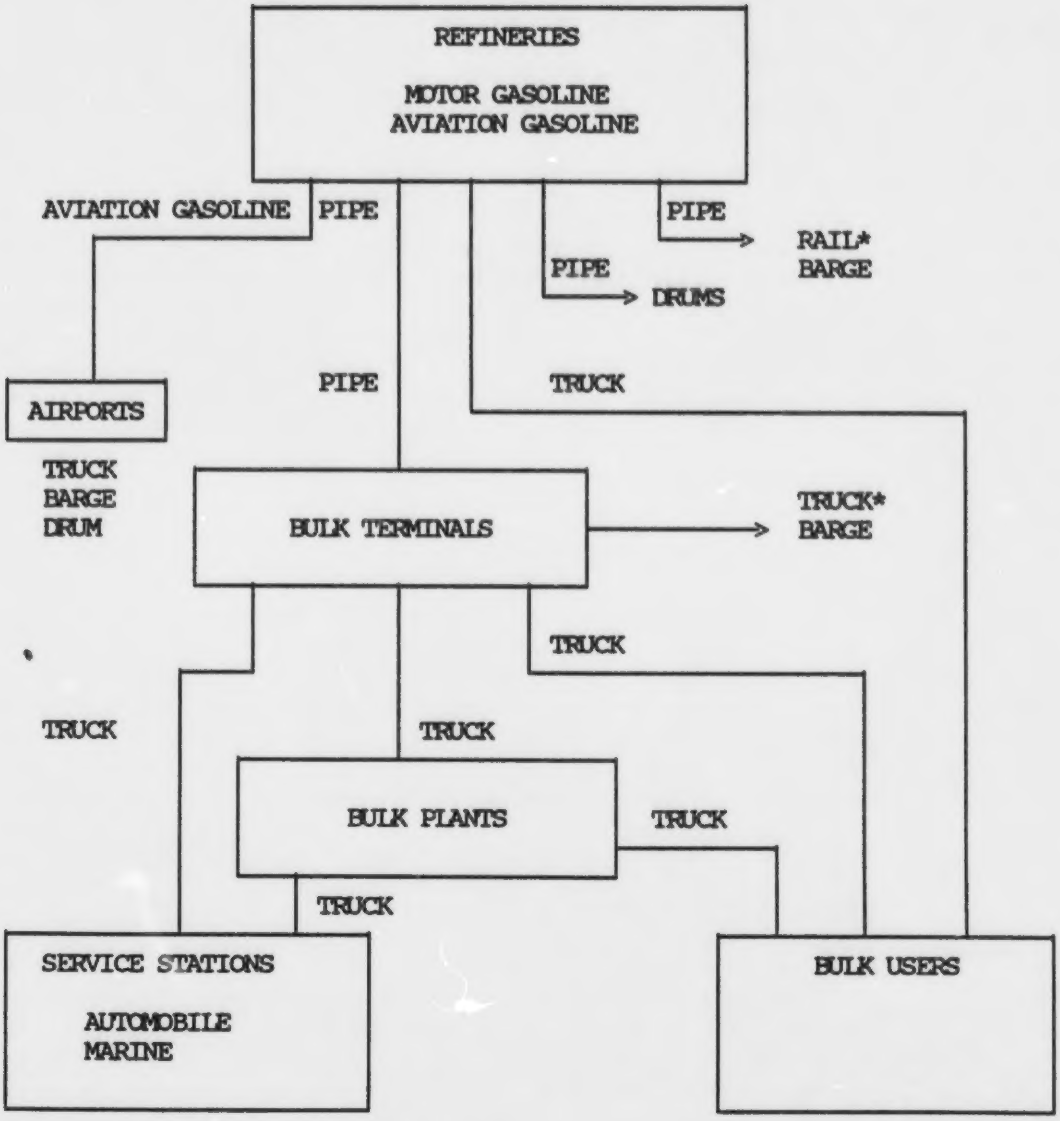
2. At Bulk Terminals

Gasoline stored at the bulk terminals may be directed to customers in a number of ways:

- by tank trucks out of the study area;
- by tank trucks directly to service stations;
- by tank trucks to bulk plants;
- by tank trucks to commercial independents and bulk users who may use secondary storage.

3. At Bulk Plants

- via tank trucks to service stations;
- via tank trucks to commercial independents;
- via truck to bulk users.


REFINERIES
MOTOR GASOLINE
AVIATION GASOLINE
AVIATION GASOLINE
PIPE
PIPE
RAIL*
BARGE
PIPE
DRUMS
AIRPORTS
PIPE
TRUCK
TRUCK
BARGE
DRUM
BULK TERMINALS
TRUCK*
BARGE
TRUCK
TRUCK
TRUCK
BULK PLANTS
TRUCK
TRUCK
SERVICE STATIONS
AUTOMOBILE
MARINE
BULK USERS

* Out of study area

FIGURE II-1 GASOLINE MARKETING NETWORK

4. Bulk Users

These users that operate dedicated refueling stations to serve their own vehicles. In most cases their annual gasoline consumption would be less than 450,000 litres.

5. Imports

Gasoline has been imported on occasion by tank truck with deliveries directly to service stations.

B. Description of the Sources of VOC Emissions

1. Above Ground Tanks

(a) Fixed Roof Tanks

Emissions from fixed roof tanks arise from breathing, filling and emptying losses.

Changes in temperature and barometric pressure without any changes in liquid level result in breathing losses. Vapour is expelled when internal tank head space temperature increases or when barometric pressure outside the tank decreases. Conversely, fresh air is drawn into the tank under the opposite conditions, causing evaporation of stored liquid and potentially, VOC emissions.

Increases in liquid level during filling result in increased tank head space pressure. Eventually the relief pressure is exceeded and the vapours are released. When tanks are emptied, fresh air is drawn into the tank then the air becomes saturated with organic vapours, expands and is discharged to the atmosphere. Filling and emptying fixed-roof tanks results in working losses.

(b) External Floating Roof Tanks

Emissions from external floating roof tanks occur as a result of withdrawal and standing storage losses from the rim seal and deck fittings. Withdrawal losses occur when a floating roof is lowered, exposing the liquid clinging to the wall, which then evaporates.

The standing storage loss is the major element of evaporative loss. It results from air flows across the top of external floating roof tanks. The mechanism involved depends on the type of seals used to close off the annular space between the floating roof and tank walls. Several types of commonly used primary and secondary seals are shown in Figure II-2.

Penetrations in the roof by deck fittings result in deck fitting losses. The most common of these fittings are: access hatches, automatic gauge float well, column well, ladder well, roof leg or hammer well and sample well. Note that there are presently no EPA approved means of calculating these losses for external floating roof tanks.

External floating roof tanks do not have deck seam losses.

(c) Internal Floating Roof Tanks

Emissions from internal floating roof tanks occur as a result of withdrawal and standing storage losses from the rim seal, deck fittings and deck seams. Withdrawal losses occur when a floating roof is lowered. The liquid clinging to the wall or columns is exposed to unsaturated air and evaporates.

Standing storage losses in internal floating roof tanks are usually only controlled by a primary seal similar to the types used for external floating roof tanks.

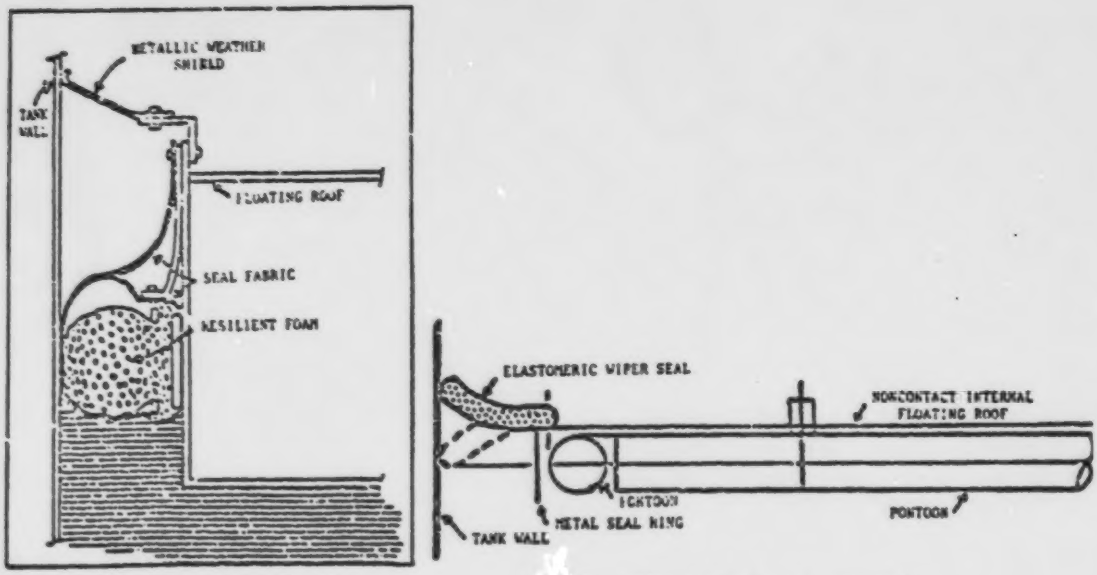
Deck fitting losses result from penetrations in the roof by deck fittings. In addition to all the fittings commonly found in external floating roofs, a vacuum breaker would also be found in an internal floating roof. Unlike external floating roof tanks, deck fitting losses from internal floating roof tanks can be calculated using correlations developed by the U.S. EPA.

The seams in the decks of internal floating roof tanks can contribute to losses to the extent that the seams are not vapour-tight. There are obviously no seam losses from welded deck internal floating roof tanks.

2. Transfer Operations

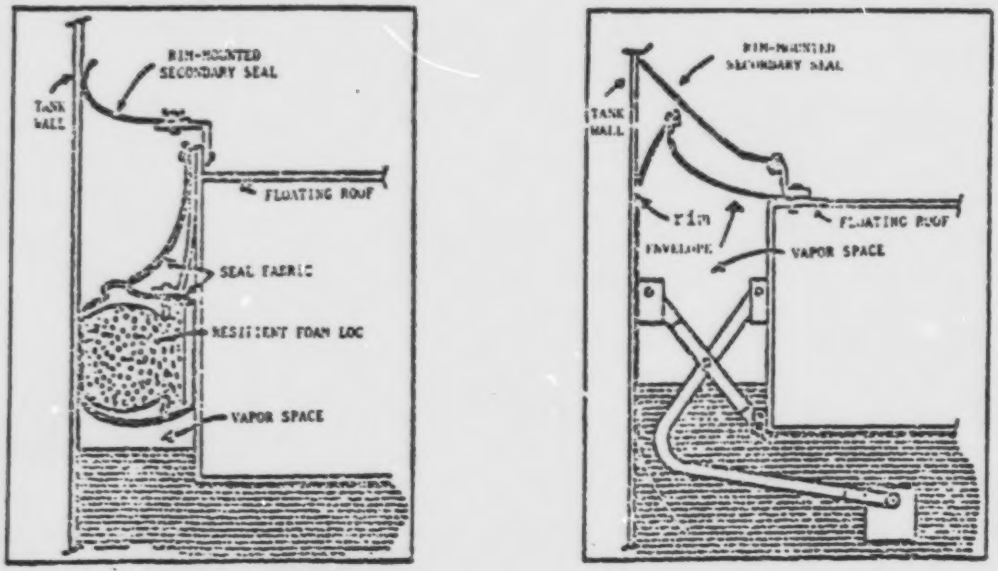
(a) Truck, Rail and Marine

The majority of VOC emissions occur during fuel loading and unloading. Vapours from an empty tank are displaced as the tank is filled. Conversely, fresh air is drawn into a tank being emptied, causing liquid product either remaining in the tank or clinging to the walls to evaporate. Vapours may be formed in the tank by evaporation of residual product from previous loads, they


METALLIC WEATHER SHIELD
TANK WALL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM
ELASTOMERIC WIPER SEAL
NONCONTACT INTERNAL FLOATING ROOF
PONTOON
METAL SEAL RING
TANK WALL
PONTOON

a. Liquid mounted seal with weather shield.

b. Elastomeric wiper seal.


RIM-MOUNTED SECONDARY SEAL
TANK WALL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM LOG
VAPOR SPACE
RIM-MOUNTED SECONDARY SEAL
TANK WALL
rim
ENVELOPE
FLOATING ROOF
VAPOR SPACE

c. Vapor mounted seal with rim mounted secondary seal.

d. Metallic shoe seal with shoe mounted secondary seal.

FIGURE II-2 PRIMARY AND SECONDARY SEAL CONFIGURATIONS FOR FLOATING ROOF TANKS

Source: US EPA-42

may be generated in that tank as the new product is loaded, or they may be transferred there from a vapour control system. The evaporative losses will then be a function of:

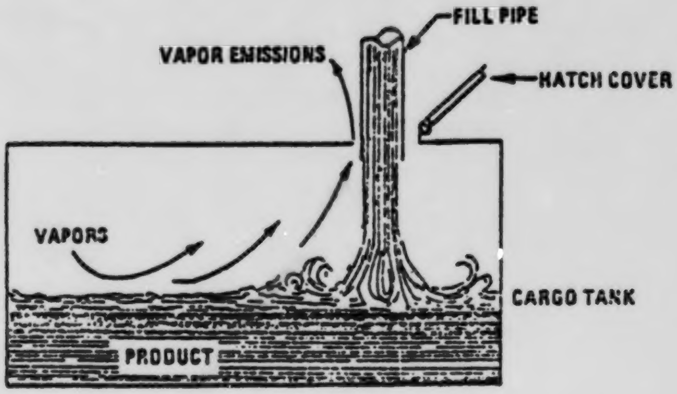
- the physical and chemical properties of the previous and the new cargos;
- the method of unloading the previous cargo and of loading the new cargo; and
- the operations to transport the empty carrier to a loading terminal.

Tanks may be filled by splash loading which generates turbulence, resulting in high levels of vapour generation and losses, or they may be filled by top or bottom submerged methods which reduce the amount of turbulence and hence the amount of vapour generation and losses. Figure II-3 shows the three types of loading schemes.

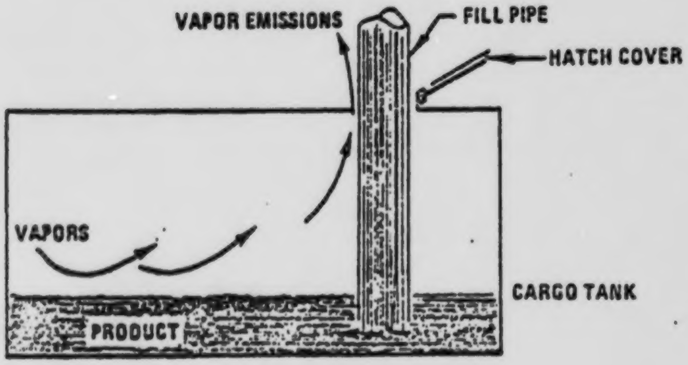
Carriers which are designated to carry only one type of product are termed "dedicated". Others may carry a variety of cargos ranging from non-volatile to highly volatile and are termed "non-dedicated". A non-volatile product being loaded may expel the vapours remaining from a previous load. The circumstances for this type of operation vary with the ownership of the carrier, the types of cargo, the geographic location and the season of the year.

Ballasting losses associated with the unloading of petroleum liquids at marine terminals occur when vessels pump sea water into unloaded tanks to maintain stability. The sea water displaces vapours as the tank is being filled, but reduces the quantity of vapours during subsequent loading of the tank with petroleum liquids. Ballasting of tankers is not used locally.

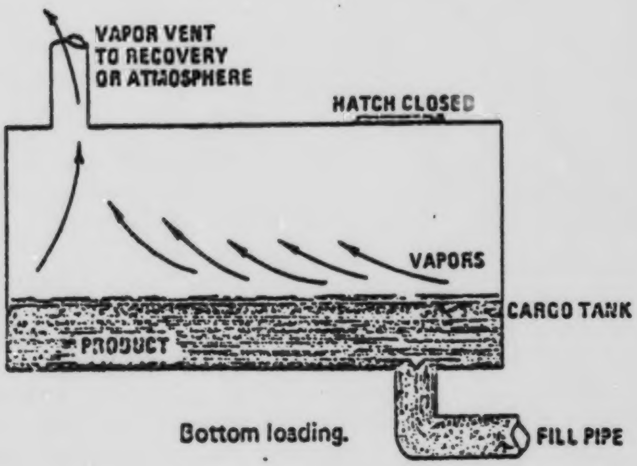
Transit losses are similar to tank breathing losses in many ways and occur while the cargo is in transit. Some of the factors which will effect the amount of emissions are the vapour tightness of the tank, pressure relief valve settings, initial pressure in the tank, the vapour pressure of the fuel being transported, and the degree of saturation of the vapour space in the tank. Note also that the amount of emissions are not directly proportional to the time spent in transit.


FILL PIPE
VAPOR EMISSIONS
HATCH COVER
VAPORS
CARGO TANK
PRODUCT

Splash loading method.


VAPOR EMISSIONS
FILL PIPE
HATCH COVER
VAPORS
CARGO TANK
PRODUCT

Submerged fill pipe.


VAPOR VENT
TO RECOVERY
OR ATMOSPHERE
HATCH CLOSED
VAPORS
CARGO TANK
PRODUCT
FILL PIPE

Bottom loading.

FIGURE II-3 LOADING METHODS

Source: US EPA-42

Transit losses are not included in the scope of this study and were not included in the inventory of emissions from gasoline marketing sources. These losses were included in the inventory of area sources in the Lower Mainland prepared by Cirrus Consultants et al (1987).

(b) Service Stations

A major source of evaporative losses comes from the filling of underground tanks at service stations. Emissions are generated by vapour displacement during loading of the underground tanks. The amount of loss depends on several factors, such as the method and rate of filling, the tank configuration and the gasoline composition, vapour pressure and temperature.

Another source of emissions is underground tank breathing. These losses are attributable to gasoline evaporation and changes in the barometric pressure, as well as the frequency of gasoline withdrawal which allows fresh air to enter the tank and enhance evaporation.

3. Motor Vehicle Refueling

Refueling of motor vehicles generates emissions by displacing the vapours from the vehicle fuel tank and by spillage during the refueling process. The gasoline temperature, vehicle tank temperature, dispensing rate and gasoline RVP all have an impact on the quantity of displaced vapours.

Prefill and postfill nozzle drip, spit-back and overflow contribute to spillage. The amount is affected by tank and tank fill-pipe configuration, operator techniques and service station business characteristics.

C. Hydrocarbon Component Speciations

Samples of regular leaded and regular unleaded gasoline were taken from an Esso station during February, 1989. Approximately 5 L of each blend of gasoline was stored in 20 L air-tight pails at about 12°C for 6 days. The vapour was drawn off into a cleaned gas sample container and shipped to the Alberta Research Council, Oil and Gas Laboratory for gas chromatographic analysis. The column they used is calibrated to measure essentially all of the hydrocarbon components in gasoline vapour. The results of the analysis will be used as preliminary speciation factors. The speciation factors for both blends as well as an average for the two blends are reported in Table II-1 as weight percent. For comparison purposes, the speciation factors reported in the Phase I report are reported in

TABLE II-1 SPECIATION FACTORS FOR AUTOMOBILE GASOLINE

	COMPONENT NAME	SAROAD CODE	UNLEADED (wt. %)	LEADED (wt. %)	AVERAGE (wt. %)
1	methane	43201	0.0066	0.0063	0.01
2	ethene	43202	0.0022	0.0021	
3	ethane	N/A	0.0367	0.0371	0.04
4	propene	43202	0.0256	0.0251	0.03
5	propane	43205	3.2338	3.2691	3.25
6	iso-butane	43204	32.4721	32.7420	32.47
7	1-butene and iso-butylene[a]	43214	2.8719	2.8935	2.88
8	normal-butane	43215	29.3896	29.3636	29.38
9	trans-2-butene	43212	2.1744	2.1760	2.18
10	2-2-dimethyl propane	43216	0.0978	0.0992	0.10
11	cis-2-butene	N/A	1.5317	1.5333	1.53
12	3 methyl-1-butene	43217	0.1353	0.1358	0.14
13	iso-pentane	43223	13.4663	13.3922	13.43
14	1-pentene	43221	0.2271	0.2259	0.23
15	2 methyl-1-butene	43224	0.5029	0.5029	0.50
16	normal pentane	43225	6.7102	6.5977	6.65
17	isoprene	43220	0.0083	0.0081	0.01
18	trans-2-pentene	43243	0.4774	0.4724	0.47
19	1-pentyne	43226	0.0087	0.0100	0.01
20	cis-2-pentene	N/A	0.2622	0.2627	0.26
21	2-methyl-2-butene	43227	0.7616	0.7524	0.76
22	trans-1,3-pentadiene	43228	0.0073	0.0072	0.01
23	1,3-pentadiene	N/A	0.0049	0.0051	0.01
24	2,2-dimethyl butane	N/A	0.2531	0.2478	0.25
25	cyclopentene	43291	0.0662	0.0653	0.07
26	2,3-pentadiene	N/A	0.0514	0.0508	0.05
27	cyclopentane	43242	0.2634	0.2565	0.26
28	1,3-dimethyl butane	N/A	0.3392	0.3320	0.34
29	hexene[b]	43245	0.4153	0.4291	0.42
30	2-methyl pentane	43229	1.4748	1.4598	1.47
31	3-methyl pentane	43230	0.8236	0.8014	0.81
32	normal hexane	43231	0.6668	0.6477	0.66
33	methyl cyclopentane	43262	0.2431	0.2494	0.25
34	2,2-dimethyl pentane	N/A	0.0172	0.0034	0.01
35	2,4-dimethyl pentane	43247	0.0519	0.0509	0.05
36	heptene[c]	43264	0.1303	0.1724	0.15
37	benzene	45201	0.2887	0.2789	0.29
38	3,3-dimethyl pentane	43248	0.0105	--	0.11
39	cyclohexane	43248	0.0431	0.0098	0.03
40	2,3-dimethyl pentane	43274	0.1176	0.1160	0.12
41	3-methyl hexane	43295	0.0788	0.0781	0.08

TABLE II-1 SPECIATION FACTORS FOR AUTOMOBILE GASOLINE (CONTINUED)

	COMPONENT NAME	SAROAD CODE	UNLEADED (wt. %)	LEADED (wt. %)	AVERAGE (wt. %)
42	trans-1,3-dimethyl cyclo pentane	N/A	0.0198	0.0200	0.02
43	cis-1,3-dimethyl cyclo pentane	N/A	0.0127	0.0126	0.01
44	3-ethyl pentane	N/A	0.0135	0.0130	0.01
45	2,2,4-trimethyl pentane	43276	0.0043	0.0041	
46	normal heptane	43232	0.0247	0.0254	0.03
47	methyl cyclo hexane	43261	0.0139	0.0142	0.01
48	ethyl cyclohexane	43288	0.0025	0.0026	
49	octene[d]	43265	0.0074	0.0081	0.01
50	2,4-dimethyl hexane	43277	0.0027	0.0028	
51	2,3,4-trimethyl pentane	43279	0.0041	0.0045	
52	toluene	45202	0.1135	0.1199	0.12
53	2-methyl heptane	N/A	0.0031	0.0040	
54	3-methyl heptane	43298	0.0024	--	
55	4-methyl heptane	43297	--	0.0021	
56	ethyl benzene	45203	0.0034	0.0038	
57	xylene	45102, 45204	0.0149	0.0179	0.02
58	propylbenzene	45108	0.0003	0.0002	
59	1-ethyl-3-methyl benzene	N/A	0.0008	0.0009	
60	1-ethyl-4-methyl benzene	N/A	0.0004	0.0004	
61	1,3,5-trimethyl benzene	45207	0.0006	0.0004	
62	1-ethyl-2-methyl benzene	N/A	0.0004	0.0002	
63	1,2,4-trimethyl benzene	45230	0.0010	0.0012	
64	1,2,3-trimethyl benzene	45230	0.0008	0.0004	
			99.9999	100	99.59

a	proportions unknown
b	isomers of hexene
c	isomers of heptene
d	isomers of octene
N/A	not available

Table II-2. Note that in both cases, "winter" gasoline supplied by Esso was used. RVP's were also similar in both cases.

The difference in magnitude of the values determined for common components in the earlier and the present vapour phase analyses is due largely to differences in the number of chemical components analyzed. Only 12 components were analyzed in the earlier test compared to over 100 in the present test. These 12 components typically comprise 70 to 90% of the total hydrocarbons in the vapour space. Since the weight fractions for the 12 components were normalized to 100%, the amount of each component was magnified by 10 to 30%. Therefore, comparisons between the two data sets should only be done qualitatively.

It should also be noted that gasoline is a mixture of components blended to give specified vapour pressures (RVP) and octane number (MON and RON). The concentration of components in the liquid gasoline could vary considerably between blends and refiners. Therefore, the analysis should not be viewed as representative of "gasoline".

D. Fuel Quantities and Emissions for the Various Sources

The movement of gasoline through the marketing network in the Lower Mainland and fuel volumes distributed at various levels are illustrated in Figure II-4. A total of 3,461,220 m^3 of gasoline was produced in 1985, but due to rehandling at intermediate distribution points, the quantity actually transferred and dispensed tripled to about 10,464,000 m^3. As a result, about 6,516.6 tonnes of VOC's were emitted in 1985. The VOC emissions and fuel quantities have been broken down into four major source types in Table II-3 and into five main points in the fuel marketing network in Table II-4. A detailed breakdown of emissions is given by source type and distribution level in Table II-5. Overall emission factors are shown for each source type.

There are over 800 sources of VOC's in the gasoline marketing network in the study area. The spatial distribution of emissions is shown by grid cell in Figure II-5 for total VOC emissions and by grid cell for VOC emissions by source type in Figures II-6 to II-9. The VOC emissions of fuel quantities by municipalities are ranked in Table II-6.

The total VOC emission level is relatively constant throughout the year as given in Figure II-10. This is somewhat surprising given that temperatures and tourist traffic are higher in the summer. Countering this tendency towards higher emissions, RVP is down which apparently has resulted in a leveling out of emissions over the year.

TABLE II-2 SPECIATION FACTORS FOR AUTOMOBILE GASOLINE - PHASE I REPORT

CHEMICAL	SAROAD NO.	WEIGHT %[a]
Butene	43213	3.04
Cis-2-Butene	43217	1.74
Ethane	43202	0.19
Ethylene	43203	0.03
Isobutane	43214	41.72
Isomers of Pentane	43122	11.94
Methane	43201	0.05
N-Butane	43212	30.99
N-Pentane	43220	4.28
Propane	43204	3.50
Propylene	43205	0.14
Trans-2-Butene	43216	2.39

[a] Average of values measured in Phase I for regular leaded, premium unleaded and regular unleaded grades of gasoline. These were normalized to 100%.

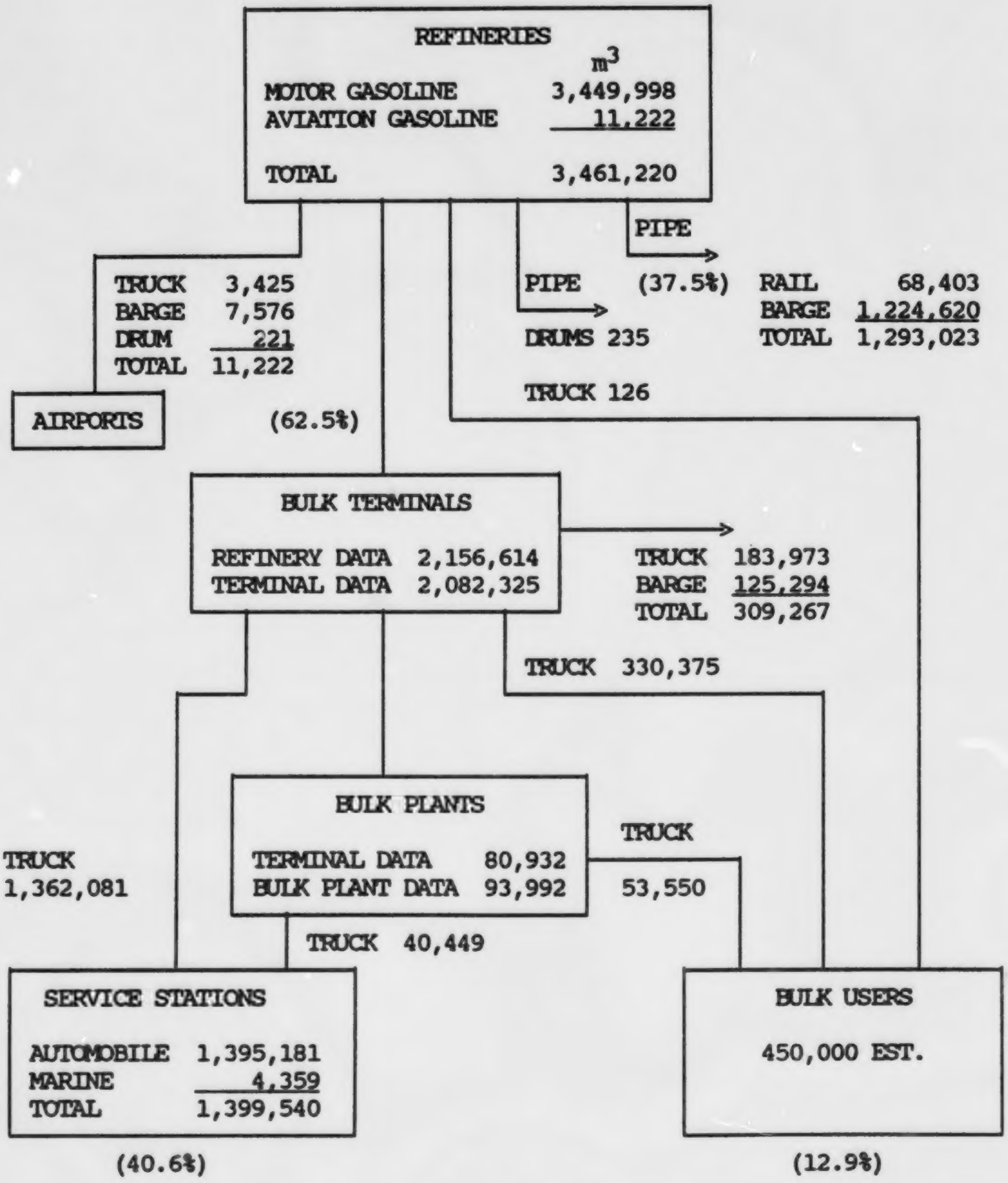

REFINERIES
m^3
MOTOR GASOLINE 3,449,998
AVIATION GASOLINE 11,222
TOTAL 3,461,220
TRUCK 3,425
BARGE 7,576
DRUM 221
TOTAL 11,222
AIRPORTS
(62.5%)
PIPE
(37.5%)
PIPE
DRUMS 235
TRUCK 126
RAIL 68,403
BARGE 1,224,620
TOTAL 1,293,023
BULK TERMINALS
REFINERY DATA 2,156,614
TERMINAL DATA 2,082,325
TRUCK 183,973
BARGE 125,294
TOTAL 309,267
TRUCK 330,375
BULK PLANTS
TERMINAL DATA 80,932
BULK PLANT DATA 93,992
TRUCK
53,550
TRUCK
1,362,081
TRUCK 40,449
SERVICE STATIONS
AUTOMOBILE 1,395,181
MARINE 4,359
TOTAL 1,399,540
(40.6%)
BULK USERS
450,000 EST.
(12.9%)

FIGURE II-4 FUEL MARKETING NETWORK FOR GASOLINE

TABLE II-3 VOC EMISSION FOR MAJOR SOURCE TYPES

SOURCE TYPE	ANNUAL FUEL THROUGHPUT (10^3m^3)	PERCENT OF TOTAL FUEL (%)	ANNUAL EMISSION (t)	PERCENT OF TOTAL EMISSIONS (%)
Tanks				
External floating roof	1,472.4	14.1	101.2	1.6
Internal floating roof	3,117.5	29.8	70.6	1.1
Fixed roof	524.3	5.0	453.8	7.0
Underground (excluding service stations)	22.9	0.2	24.1	0.4
Subtotal	5,137.1	49.1	649.7	10.1
Loading Operations				
Truck	2,050.7	19.6	1,226.6	18.8
Railcar	68.4	0.7	41.5	0.6
Barge and ship	1,357.5	13.0	599.8	9.2
Subtotal	3,476.6	33.2	1,867.9	28.6
Service Stations				
Automobile	1,395.2	13.3	3,023.0	46.4
Aircraft	0.7	0.0	1.3	0.02
Marine Vessels	4.3	0.0	9.2	0.1
Subtotal	1,400.2	13.4	3,033.5	46.5
Bulk Users (dedicated service stations)	450.0	4.3	965.5	14.8
Total	10,463.9	100	6,516.6	100

TABLE II-4 VOC EMISSIONS FOR MAIN POINTS IN THE FUEL MARKETING NETWORK

SOURCE TYPE	ANNUAL FUEL THROUGHPUT ($10^3 m^3$)	PERCENT OF TOTAL FUEL (%)	ANNUAL EMISSION (t)	PERCENT OF TOTAL EMISSIONS (%)
Refineries	4,709.0	45.0	774.4	11.9
Bulk Terminals	3,708.5	35.4	1,592.8	24.4
Bulk Plants	196.2	1.9	150.4	2.3
Service Stations (all types)	1,400.2	13.4	3,033.5	46.6
Bulk Users	450.0	4.3	965.5	14.8
Total	10,463.9	100	6,516.6	100

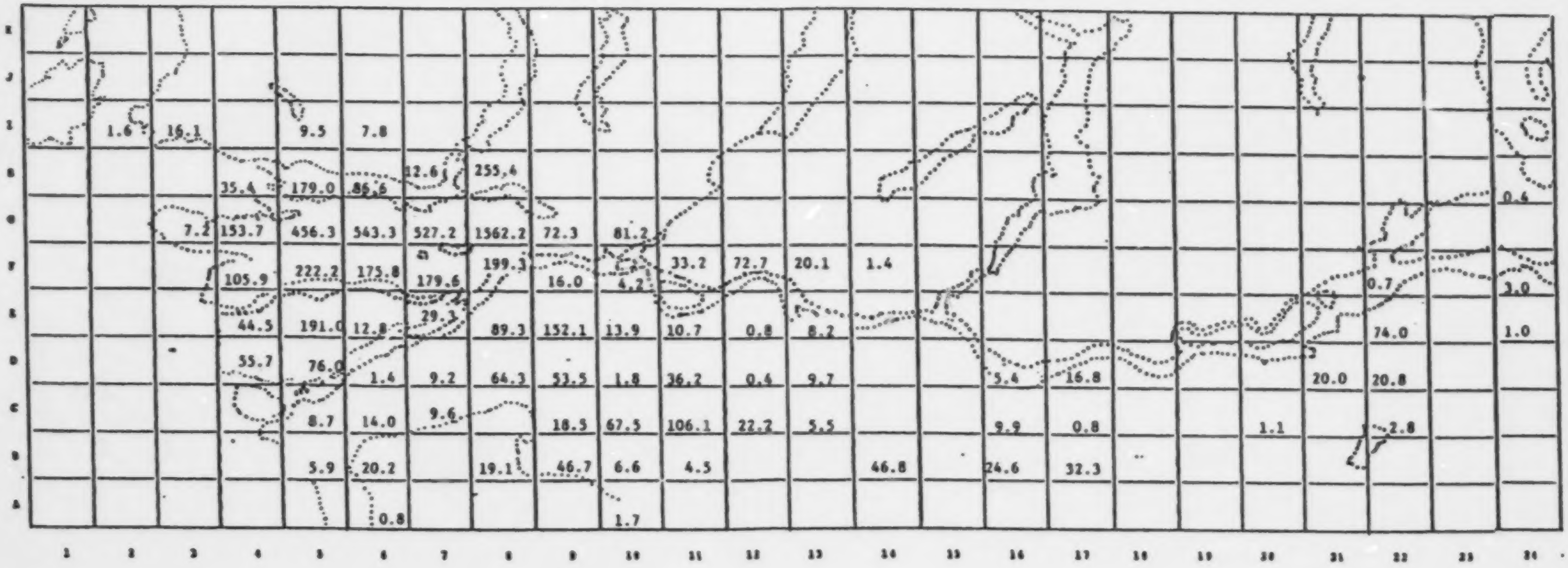
TABLE II-5 DETAILED BREAKDOWN OF EMISSIONS AND FUEL THROUGHPUTS

SOURCE TYPE	ANNUAL FUEL THROUGHPUT (m^3)	ANNUAL EMISSION (t)	OVERALL EMISSION FACTOR (kg/m^3)
TANKAGE			
Refinery			
External floating roof	1,472,413	101.21	0.07
Internal floating roof	1,921,124	56.97	0.03
Fixed roof	12,329	31.72	2.57
Subtotal	3,405,865	189.90	
Bulk Terminal			
External floating roof	nil	nil	--
Internal floating roof	1,196,389	13.65	0.01
Fixed roof	436,803	354.26	0.81
Subtotal	1,633,192	367.91	
Bulk Plant			
Fixed roof	75,137	67.77	0.90
Underground tank	22,894	24.14	1.05
Subtotal	98,031	91.91	0.938
Total Tankage	5,137,088	649.72	0.132

- continued -

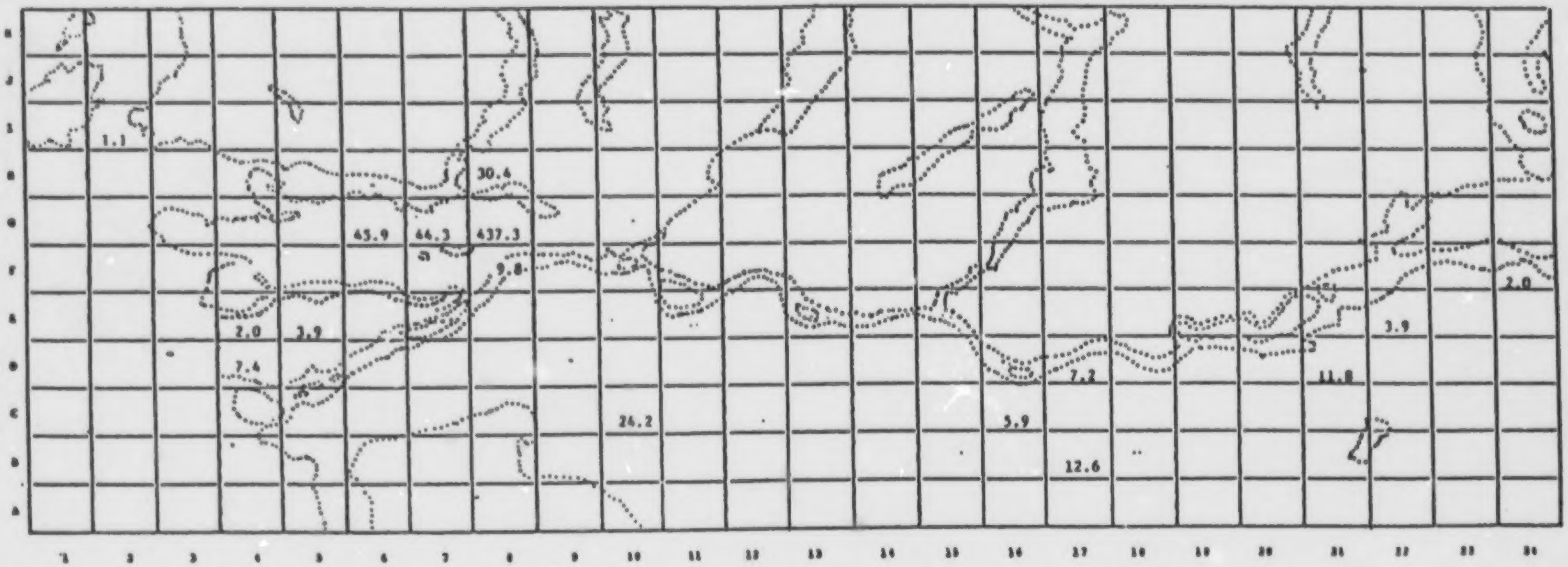
TABLE II-5 DETAILED BREAKDOWN OF EMISSIONS AND FUEL THROUGHPUTS (CONTINUED)

SOURCE TYPE	ANNUAL FUEL THROUGHPUT (m^3)	ANNUAL EMISSION (t)	OVERALL EMISSION FACTOR (kg/m^3)
BULK TRANSFER			
Ship/Barge loading	1,357,490	599.82	0.44
Railcar loading	68,404	41.49	0.61
Truck loading			
At bulk plant	98,199	58.50	0.60
At terminal	1,949,964	1,166.63	0.60
At refinery	2,586	1.46	0.60
Total truck loading	2,050,749	1,226.59	
Total Bulk Transfer	3,476,643	1,867.90	
SERVICE STATION			
Aircraft (Avgas)	704	1.25	1.78
Marine	4,359	9.22	2.12
Passenger Vehicles	1,395,181	3,023.02	2.17
Total Service Station	1,400,244	3,033.49	
BULK END USERS	449,987	965.46	2.17
Totals	10,463,962	6,516.57	


K
J
I
H
G
F
E
D
C
B
A
1.6
16.1
9.5
7.8
12.6
255.4
35.4
179.0
86.6
7.2
153.7
456.3
543.3
527.2
1562.2
72.3
81.2
0.6
199.3
33.2
72.7
20.1
1.4
105.9
222.2
175.8
179.6
16.0
4.2
0.7
3.0
29.3
44.5
191.0
12.8
89.3
152.1
13.9
10.7
0.8
8.2
74.0
1.0
55.7
76.0
1.4
9.2
64.3
53.5
1.8
36.2
0.4
9.7
5.4
16.8
20.0
20.8
9.6
8.7
14.0
18.5
67.5
106.1
22.2
5.5
9.9
0.8
1.1
2.8
5.9
20.2
19.1
46.7
6.6
4.5
46.8
24.6
32.3
0.8
1.7
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

TOTAL: 6516.6 t

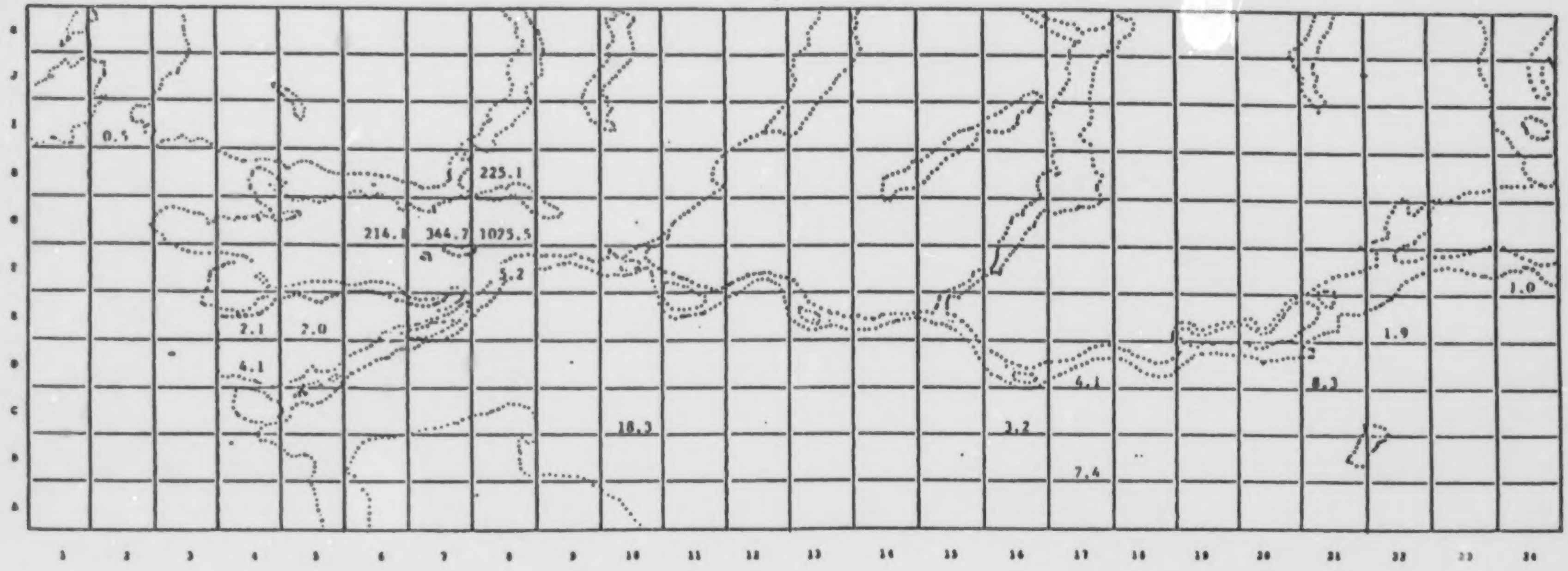
FIGURE II-5 TOTAL VOC EMISSIONS BY GRID CELL



K
J
I
H
G
F
E
D
C
B
A
1.1
30.4
45.9
44.3
437.3
9.8
2.0
3.9
7.4
24.2
5.9
12.6
7.2
11.8
3.9
2.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

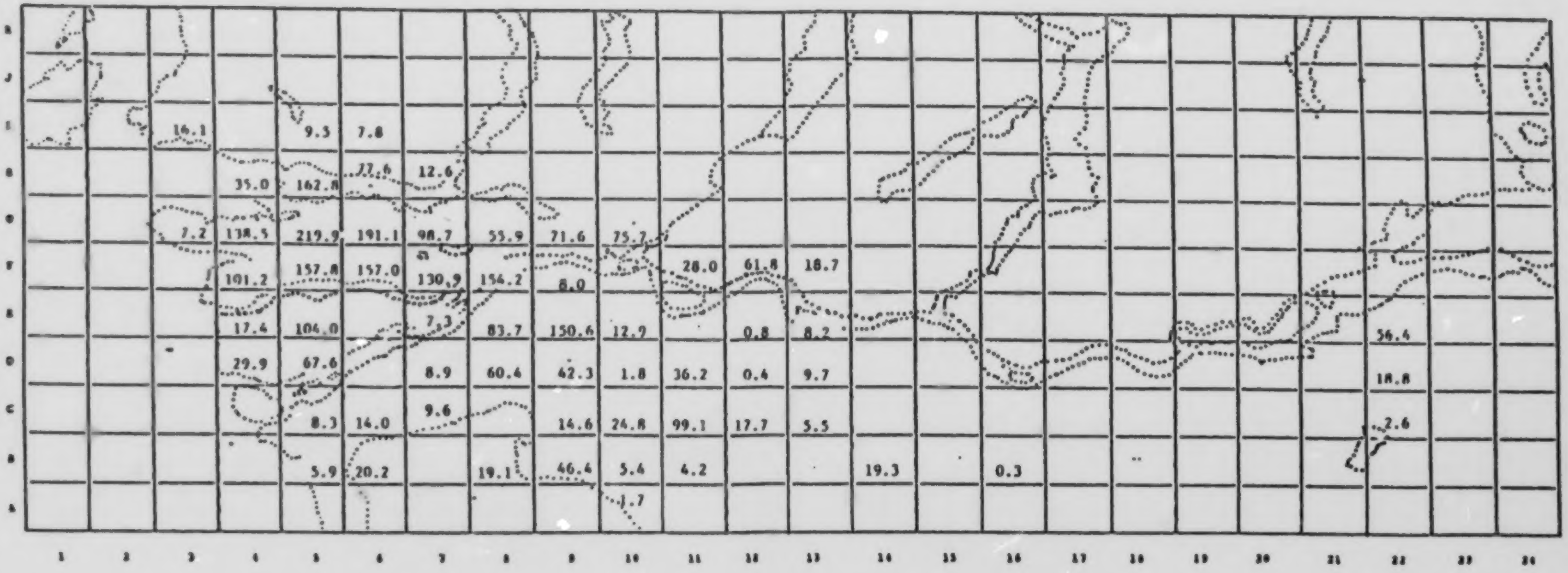
TOTAL: 649.7 t

FIGURE II-6 TOTAL VOC EMISSIONS FROM ALL TYPES OF TANKS BY GRID CELL


0.5
225.1
214.1
344.7
1025.5
3.2
2.1
2.0
4.1
18.3
3.2
7.4
4.1
8.3
1.9
1.0
K
J
I
H
G
F
E
D
C
B
A
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

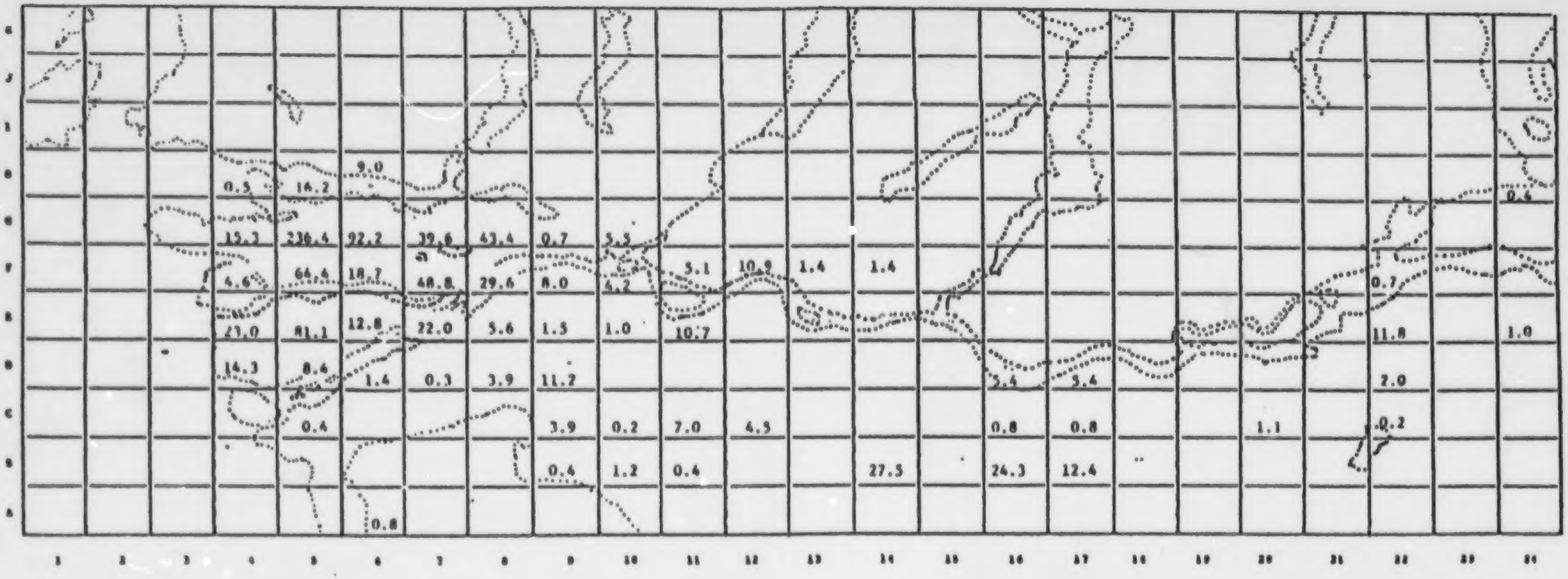
TOTAL: 1867.9 t

FIGURE II-7 TOTAL VOC EMISSIONS FROM ALL BULK TRANSFER OPERATIONS BY GRID CELL


K
J
I
H
G
F
E
D
C
B
A
16.1
9.3
7.8
35.0
162.8
22.6
12.6
7.2
138.5
219.9
191.1
98.7
55.9
71.6
75.7
101.2
157.8
157.0
130.9
154.2
8.0
28.0
61.8
18.7
17.4
104.0
7.3
83.7
150.6
12.9
0.8
8.2
56.4
29.9
67.6
8.9
60.4
42.3
1.8
36.2
0.4
9.7
18.8
8.3
14.0
9.6
14.6
24.8
99.1
17.7
5.5
2.6
5.9
20.2
19.1
46.4
5.4
4.2
19.3
0.3
1.7
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

TOTAL: 3033.5 t

FIGURE II-8 TOTAL VOC EMISSIONS FROM ALL SERVICE STATIONS BY GRID CELL


9.0
0.5
16.2
0.4
15.3
236.4
92.2
39.6
43.4
0.7
5.5
4.6
64.6
18.7
48.8
29.6
8.0
4.2
5.1
10.9
1.4
1.4
0.7
23.0
81.1
12.8
22.0
5.6
1.5
1.0
10.7
11.8
1.0
14.3
8.4
1.4
0.3
3.9
11.2
5.4
5.4
2.0
0.4
3.9
0.2
7.0
4.5
0.8
0.8
1.1
0.2
0.4
1.2
0.4
27.5
24.3
12.4
0.8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24

TOTAL: 965.5 t

FIGURE II-9 TOTAL VOC EMISSIONS FROM BULK END USERS BY GRID CELL

TABLE II-6 VOC EMISSIONS BY MUNICIPALITY

RANKING	MUNICIPALITY OR CITY	ANNUAL VOC EMISSIONS (t)	PERCENT OF TOTAL (%)
1	Burnaby	1,963.6	30.1
2	Vancouver	1,324.1	20.3
3	Port Moody	653.9	10.0
4	Surrey	480.3	7.4
5	Richmond	400.5	6.1
6	Ioco-Anmore-Seymour (Area B)	255.4	3.9
7	North Vancouver District	171.9	2.6
8	New Westminster	148.8	2.3
9	Delta	139.2	2.1
10	Langley District	136.7	2.1
11	Coquitlam	131.2	2.0
12	Chilliwack	120.4	1.8
13	North Vancouver City	105.1	1.6
14	Maple Ridge	100.7	1.5
15	Port Coquitlam	82.6	1.3
16	West Vancouver	69.9	1.1
17	Langley City	64.9	1.0
18	Abbotsford	56.9	0.9
19	White Rock	42.7	0.7
20	Pitt Meadows	26.6	0.4
21	Mission	22.2	0.3
22	Matsqui	10.6	0.2
23	University of B.C.	3.4	0.05
24	Kent	3.4	0.05
25	Bowen Island (Area C)	1.6	0.02
	Total	6,516.6	

The first seven municipalities have 80.4% of the total VOC emission in the Study area.

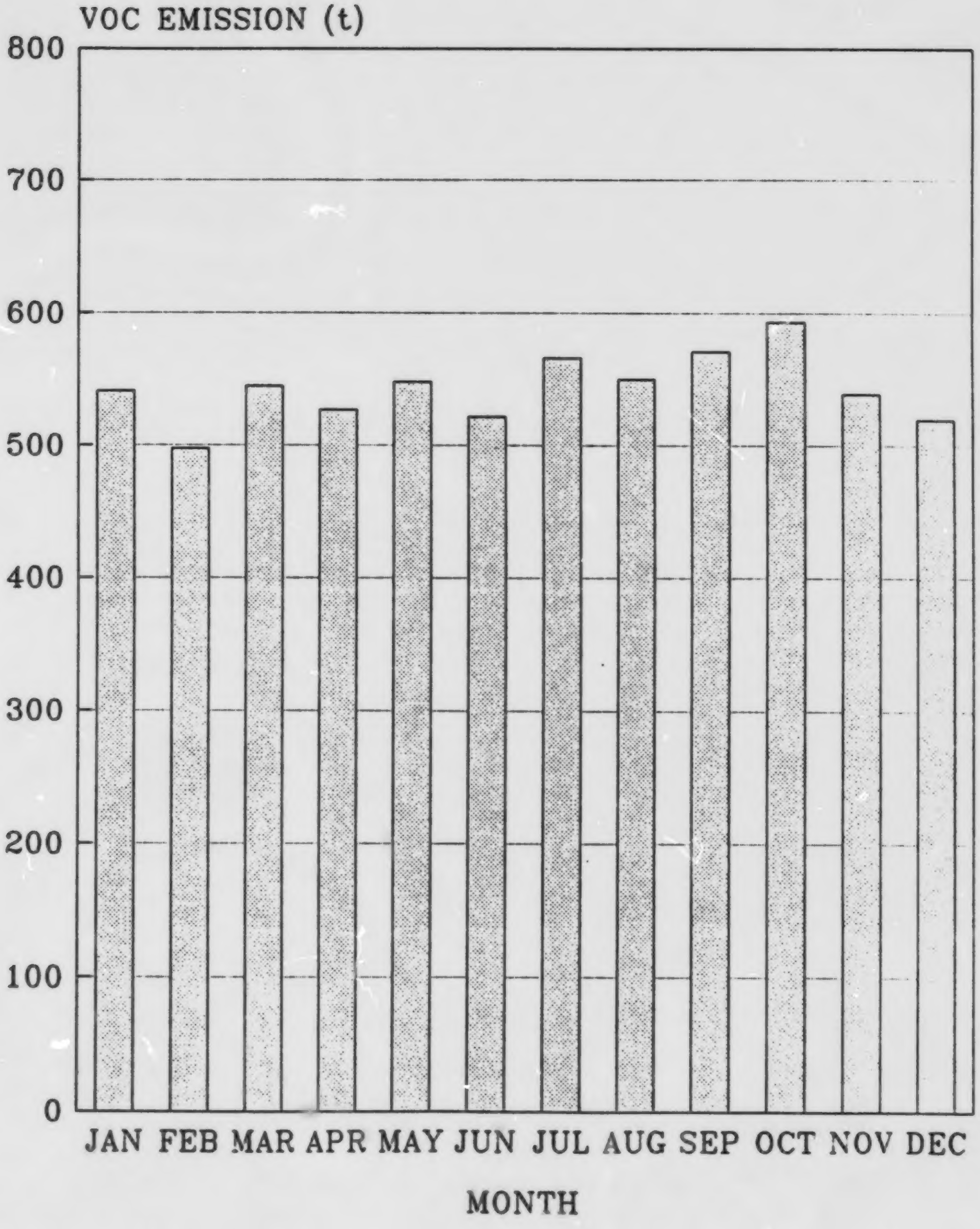


FIGURE II-10 MONTHLY TOTAL VOC EMISSIONS FROM ALL SOURCES

Emissions tend to drop off slightly on weekends and have a bimodel distribution during daylight hours as seen in Figure II-11 and II-12.

The significance of each of the over 800 sources included in the inventory varies two orders of magnitude from 0.02% to 5.4% of the total emitted. The 11 largest sources in the Lower Mainland listed in Table II-7, each emit over 50 tonnes/year and account for 31.9% of the total emissions. Some 600 service stations emit a combined 46.4% of the total VOC emissions. The source types are listed in order of rank in Table II-8 together with the associated fuel quantities. The various sources are ranked by emission factor in Table II-9.

Based on the speciation factors presented in Table II-1, the approximate order of magnitude estimates of benzene, toluene and xylene emissions are reported in Table II-10. The emissions for each of the aromatics was determined by multiplying the total VOC emissions in tonnes by the weight percent for each component divided by 100.

E. Sources Selected for Study of Control Options

The source types having the top four annual emission levels, excluding bulk users since they are individually small, were selected for study of control options. These sources emitted 81.4% of the annual total of 6516.6 tonnes in 1985, with individual contributions as follows:

	Annual Emission (t)	Percent of Total (%)
Automobile service stations	3023.0	46.4
Truck loading (all)	1226.6	18.8
Barge and ship loading	599.8	9.2
Fixed roof tanks	453.8	7.0
	5303.2	81.4

Sources considered at automobile service stations include the working losses of the underground tank, vehicle refueling losses and spillage. These three sources of vapour emissions are included in the total service station emissions.

Emissions from truck loading operations are included. The largest emission of this type occurs at bulk terminals where gasoline

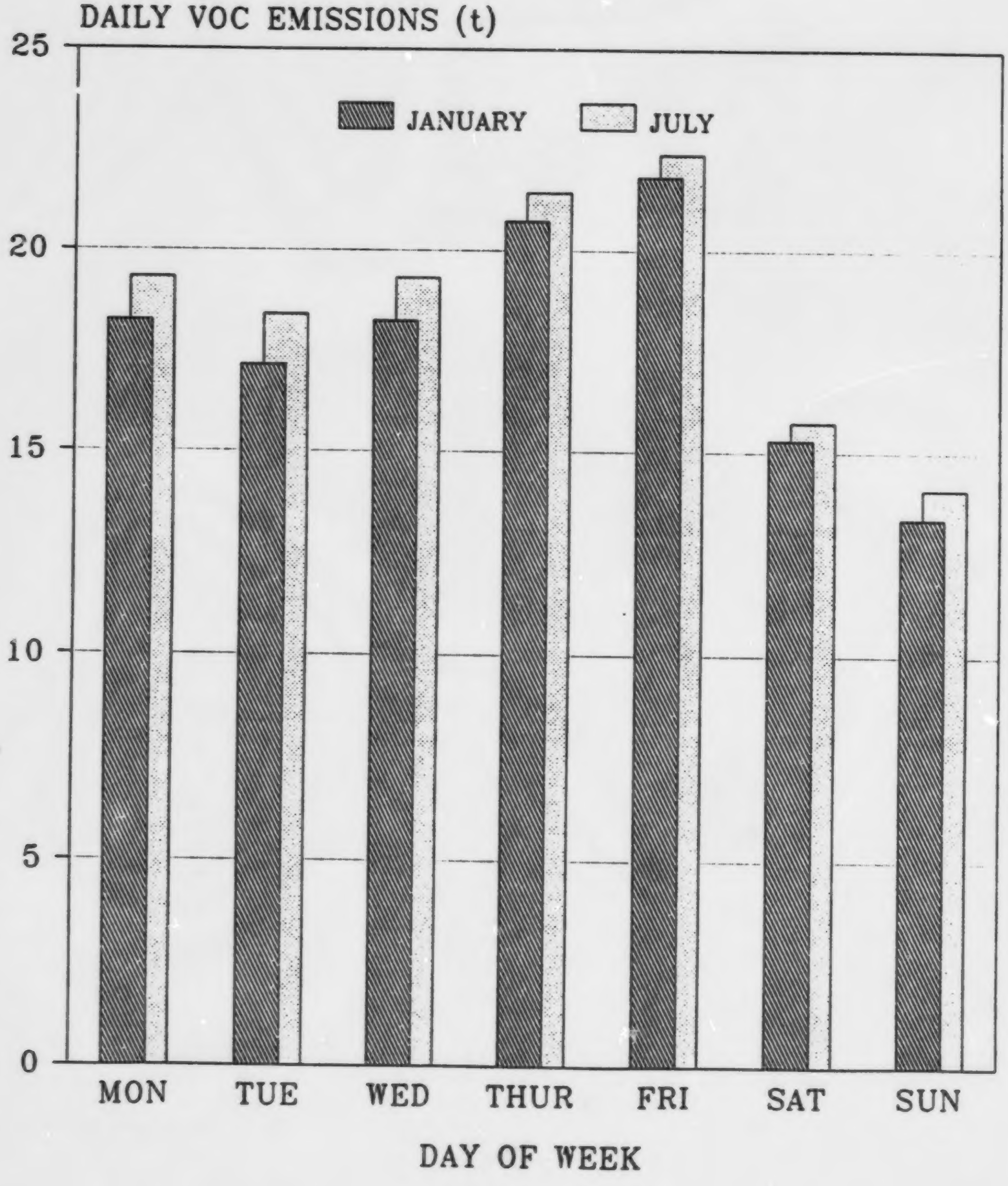


FIGURE II-11 DAILY VOC EMISSIONS FROM ALL SOURCES FOR A WEDNESDAY IN JANUARY AND JULY

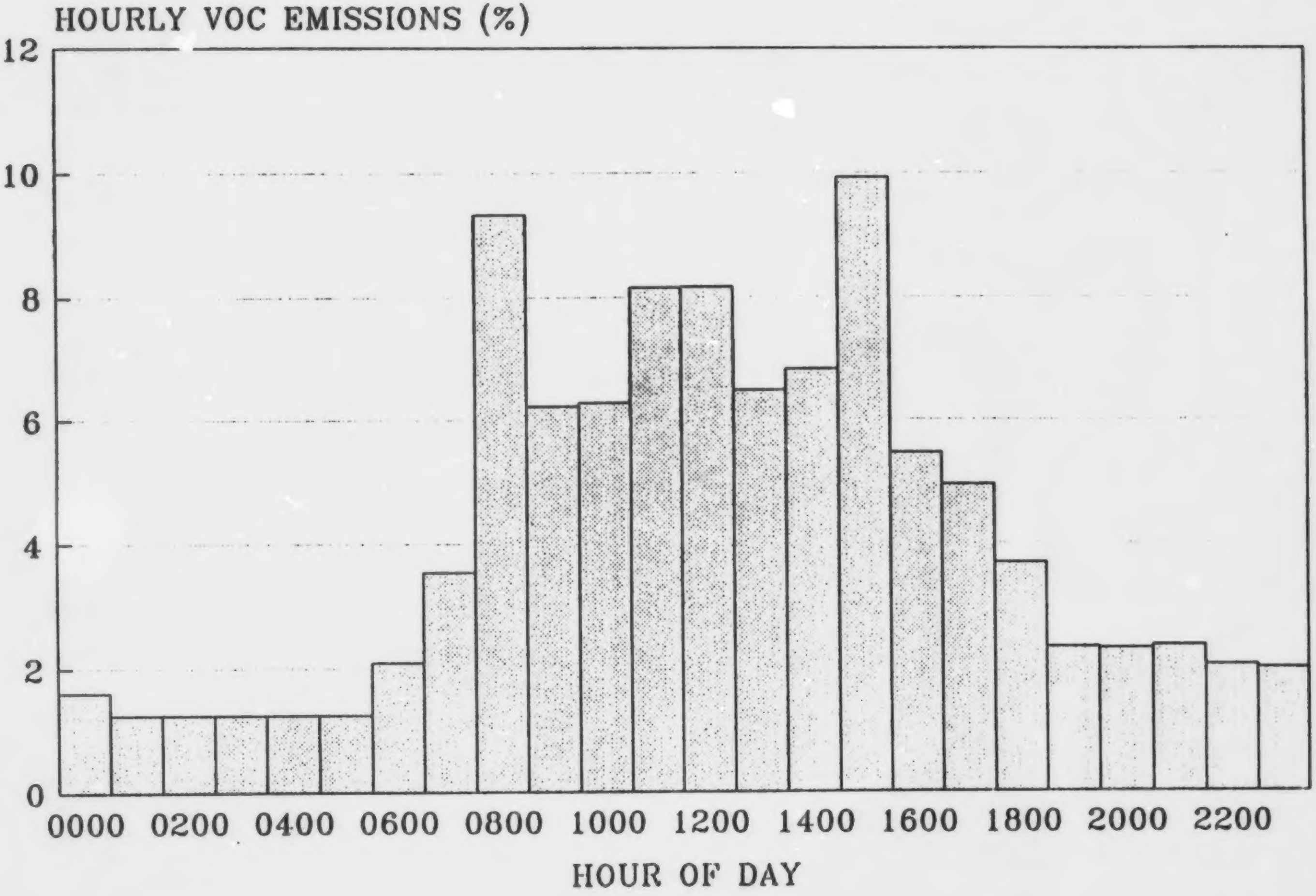


FIGURE II-12 HOURLY VARIATIONS IN VOC EMISSIONS FROM ALL SOURCES FOR A WEDNESDAY IN JULY

TABLE II-7 SOURCES EMITTING GREATER THAN 50 t/year OF VOC

RANK BY ANNUAL EMISSION		SOURCE TYPE	MUNICIPALITY	ANNUAL FUEL THROUGHPUT (10^3m^3)	ANNUAL EMISSION (t)
1.	Petro-Canada Products Bulk Terminal	Truck loading	Port Moody	585.7	349.7
2.	Esso Petroleum Canada Bulk Terminal	Truck loading	Burnaby	538.7	322.4
3.	Chevron Canada Ltd. Bulk Terminal	Truck loading	Burnaby	441.1	265.4
4.	Shell Canada Products Bulk Terminal	Truck loading	Burnaby	383.5	229.2
5.	Esso Petroleum Canada Refinery	Barge loading	Port Moody	461.4	216.6
6.	Chevron Canada Ltd. Refinery	Barge loading	Burnaby	384.1	179.3
7.	Shell Canada Products Bulk Terminal	Fixed roof tank	Burnaby	218.3	136.9
8.	Petro-Canada Products Refinery	Barge loading	Port Moody	334.8	124.3
9.	Shell Canada Products Bulk Terminal	Fixed roof tank	Burnaby	128.4	110.2
10.	Shell Canada Products Refinery	Barge loading	Burnaby	169.6	78.9
11.	Petro-Canada Products Bulk Terminal	Fixed roof tank	Port Moody	53.3	64.5
	Total				2,077.4

TABLE II-8 VOC EMISSIONS BY SOURCE TYPE IN ORDER OF RANK

RANK BY ANNUAL EMISSION	SOURCE TYPE	NUMBER OF SOURCES	ANNUAL FUEL THROUGHPUT (10^3m^3)	ANNUAL EMISSION (t)	PERCENT OF TOTAL (%)
1	Automobile service stations	600	1395.2	3023.0	46.4
2	Truck loading	24	2050.7	1226.6	18.8
3	Bulk users	60[a]	450.00	965.5	14.8
4	Barge and ship loading	4	1357.5	599.8	9.2
5	Fixed roof tanks	53	524.3	453.8	7.0
6	External floating roof tanks	17	1472.4	101.2	1.6
7	Internal floating roof tanks	18	3117.5	70.6	1.1
8	Railcar loading	3	68.4	41.5	0.6
9	Underground tanks (excluding service stations)	3	22.9	24.1	0.4
10	Marine vessel service stations	12	4.3	9.2	0.1
11	Aircraft service stations	3	0.7	1.3	0.02
				6516.6	100

[a] Number of cells only

TABLE II-9 AVERAGE EMISSION FACTORS BY SOURCE TYPE IN ORDER OF RANK

RANK	SOURCE TYPE	NUMBER OF SOURCES	EMISSION FACTOR (kg/m^3)	ANNUAL EMISSIONS (t)		ANNUAL FUEL THROUGHPUT (10^{3}m^3)
				TOTAL	PER SOURCE	
1	Automobile service stations	600	2.17	3023.0	5.04	1395.2
2	Bulk users	60[a]	2.15	965.5	--	450.0
3	Marine vessel service stations	12	2.12	9.2	0.77	4.3
4	Aircraft service stations	3	1.78	1.3	0.43	0.7
5	Underground tanks (excluding service stations)	3 (number of sites only)	1.05	24.1	8.03	22.9
6	Fixed roof tanks	53	0.87	453.8	8.56	524.3
7	Truck loading	24	0.60	1226.6	51.11	2050.7
8	Railcar loading	3	0.61	41.5	13.8	68.4
9	Barge and ship loading	4	0.44	599.8	149.95	1357.5
10	External floating roof tanks	17	0.07	101.2	5.89	1472.4
11	Internal floating roof tanks	18	0.03	70.6	3.92	3117.5
				6516.6		10463.9

[a] Number of cells only

TABLE II-10 ANNUAL EMISSIONS OF BENZENE, TOLUENE AND XYLENES

CHEMICAL	ANNUAL EMISSIONS (tonnes)	PERCENT OF TOTAL VOC (%)
VOC	6,516.6	100
Benzene	18.9	0.29
Toluene	7.8	0.12
Xylene	1.3	0.02
Total benzene, toluene, xylene	28.0	0.43

is shipped predominantly by this means. Significant truck loading emissions also occur at refineries and bulk plants.

Ships and barges are loaded at the four refineries in the study area. Large volumes of gasoline are loaded into barges and ships in a relatively short time frame, resulting in the highest emission rates on a point source basis.

Control options for fixed roof tanks fall into two categories. Internal floating roof tanks could be retrofitted at four large fixed roof tanks located at bulk terminals and seven medium sized fixed roof tanks at refineries. This control option is considered later. For small tanks, considered to be those having capacities of 150 m^3 or less, floating roofs are not cost effective (Burr et al, 1977, Shedd et al, 1977). For these tanks, balanced loading or other control strategies are considered.

III. SPECIFICATIONS FOR SOURCE CONTROL SYSTEMS

A. Characteristics of Selected Sources

1. Storage Tanks

Data obtained during preparation of the VOC emissions inventory for gasoline marketing sources show that there are 88 above-ground tanks at refineries, bulk terminals and bulk plants for storing aviation and automobile gasoline. Underground tanks are used at three bulk plants. The number and combined throughput of the above-ground tanks in the study area are itemized in Table III-1 according to the location in the gasoline marketing network. Table III-2 summarizes information on the diameter, capacity and individual throughput of above-ground tanks in the study area for each part of the marketing network.

Of the 53 fixed roof tanks used in the marketing network, 42 are at 15 of the 18 bulk plants in the Lower Mainland. The remaining 3 bulk plants use underground storage tanks. Seven fixed roof tanks are used at refineries to store aviation gasoline, which has a lower vapour pressure than automobile gasoline. The fixed roof tanks at refineries and bulk plants account for 21.9% of the emissions from fixed roof tanks, the balance being from four such tanks located at bulk terminals. These four tanks are used to store automobile gasoline.

About 90% of the combined throughput of above-ground tankage occurs in tanks equipped with either external or internal floating roofs. Because of the relatively low emission factors for these types of tanks, they account for only 26.3% of all VOC emissions from tank sources and only 2.7% of total VOC emissions from gasoline marketing in the Lower Mainland.

The largest fixed roof tanks used for gasoline storage are located at bulk terminals. Their capacity ranges from 2,400 m^3 to 4,300 m^3. The 53 fixed roof tanks located at bulk plants are all relatively small, being all less than 136 m^3 and typically near 60 m^3.

2. Bulk Transfer of Gasoline

Gasoline is shipped by truck, ship, barge and rail with transfers occurring at refineries, bulk terminals and bulk plants. Table III-3 shows the types of transfer operations taking place at the three points in the gasoline marketing network and the quantities handled in 1985. Over 90% of the

TABLE III-1 NUMBER AND ANNUAL THROUGHPUT OF GASOLINE STORAGE TANKS

LOCATION AND TANK TYPE	NUMBER	ANNUAL THROUGHPUT ($10^3 m^3$)
Refineries		
Fixed roof	7	12.3
External floating roof	17	1472.4
Internal floating roof	13	1921.1
	37	
Bulk Terminals		
Fixed roof	4	436.8
Internal floating roof	5	1196.4
	9	
Bulk Plants		
Fixed roof	42	75.1
Totals of all tanks by type:		
Fixed roof	53	524.2
External floating roof	17	1472.4
Internal floating roof	18	3117.5
	88	

TABLE III-2 SIZE OF STORAGE TANKS AT REFINERIES, BULK TERMINALS AND BULK PLANTS

LOCATION AND TANK TYPE	TANK SIZE		THROUGHPUT (m^3/yr/tank)	
	DIAMETER (m^3)	CAPACITY (m^3)	AVERAGE	RANGE
Refineries				
Fixed roof	5.8 - 15.2	250 - 1800	1760	500 - 4500
External floating roof	9.6 - 36.6	600 - 15400	92500	8000 - 348000
Internal floating roof	10.7 - 36.6	4800 - 14800	140100	11500 - 626600
Bulk Terminals				
Fixed roof	14.6 - 24.4	2400 - 4300	109200	36800 - 218300
Internal floating roof	13.0 - 36.6	1500 - 12700	239300	48000 - 426400
Bulk Plants				
Fixed roof	2.6 - 4.8	38 - 136	1770	220 - 4100

TABLE III-3 BULK LOADING OF GASOLINE

SOURCE TYPE	THROUGHPUT ($10^3 m^3$)			
	REFINERY	TERMINAL	BULK PLANT	TOTAL
Truck	2.6	1950.0	98.2	2050.8
Ship/Barge	1232.2	125.3		1357.5
Rail	68.4			68.4
Total	1303.2	2075.3	98.2	3476.7

total gasoline transferred was handled by truck at the four terminals, and by ship or barge at the four refineries.

Transfers by truck at all locations accounted for about 59% of the total gasoline shipped. Ship, barge and rail transfers accounted for the remaining 39% and 2%, respectively.

Transfers taking place at bulk terminals account for almost 60% of the total shipments. Transfers at the refinery and at bulk plants account for the remaining 37% and 3% respectively.

The volume of gasoline transferred at the four refineries in 1985 ranged from 170,000 m^3/yr to 480,000 m^3/yr. Total VOC emissions at these sites ranged from 79 t/yr to 223 t/yr. The bulk of the gasoline loaded at refineries is shipped via ship or barge (95%), generating 92.7% of the transfer emissions at refineries.

The four terminals transferred from 380,000 m^3/yr to 710,000 m^3/yr of gasoline, resulting in associated VOC emissions ranging from 215 t/yr to 390 t/yr. The bulk of the gasoline was transferred via truck (95%), making such transfers the dominant source of transfer emissions at terminals.

By comparison, the maximum amount of gasoline transferred at the 18 bulk plants was 15,500 m^3/yr. The associated VOC emission was 9.3 t/yr.

In essence, there are eight main bulk transfer operations in the study area; by ship or barge at the four refineries and by truck at the four terminals. One of the bulk terminals reported a barge/ship loading volume at a facility shared with the same company's refinery. The gasoline transfers to barges/ships from the refinery and the adjacent bulk terminal in this case have been left separate, as reported, though perhaps more properly, the quantity transferred at the terminal could be assigned to the refinery operation. If this is done, bulk transfers of bulk terminals arise exclusively from truck loading operations.

3. Service Stations

Using survey data collected for 1985 by Kent Marketing, 600 automobile service stations are located in the study area. Since the Kent Marketing data does not cover the entire Lower Mainland, some outlying municipalities are not included in the inventory. Presumably, the quantity of gasoline marketed there is comparably small in relation to the total and will, therefore, not significantly affect the overall accuracy. The gasoline sold at these stations is included in the quantity attributed to bulk users since it was calculated as the difference between the quantity known to have been produced at the refineries and the amount totalled from records for all other sources. The VOC emission from bulk users was calculated using the same emission factor as that for automobile service stations. Thus, the calculated total for VOC emissions from all sources is correct, but a small part of the emissions attributed to bulk users should in fact be associated with automobile service stations. This distortion of the emissions from parts of the gasoline distribution network is believed to be minor.

Gasoline distributed to road vehicles accounts for over 99% of the total gasoline volumes handled at service stations. The remainder is distributed to marine and airport stations. Using the detailed throughput statistics for the service stations in the study area, the average station size was found to be 2340 m^3/yr, with a small number of stations having throughputs as high as 7330 m^3/yr (Table III-4). The cumulative distribution of gasoline throughputs is almost linear from 0 to 3000 m^3/yr (Figure III-1). This range covers about 70% of the total number in the inventory. At larger sizes the distribution curve becomes non-linear. About 53% of the stations had throughputs less than the average of 2340 m^3/yr. The median station has a throughput of 2050 m^3/yr.

TABLE III-4 SERVICE STATION GASOLINE THROUGHPUTS

Number of Stations	Throughput			
	Total ($10^3 m^3$/yr)	Average (m^3/yr/station)	Median (m^3/yr/station)	Range (m^3/yr/station)
599	1,400.2	2340	2050	0 - 7330

The economics of control of VOC emissions from refueling of motor vehicles is affected by the number of nozzles used, the layout of the pumps relative to tankage and the station throughput among other factors. Data in the Kent Marketing reports were used to determine averages and ranges for the service station statistics needed to develop cost estimates for control options. The information used was for 1985.

Statistics were extracted from Kent Marketing reports for 91 service stations operated by a major oil company in the study

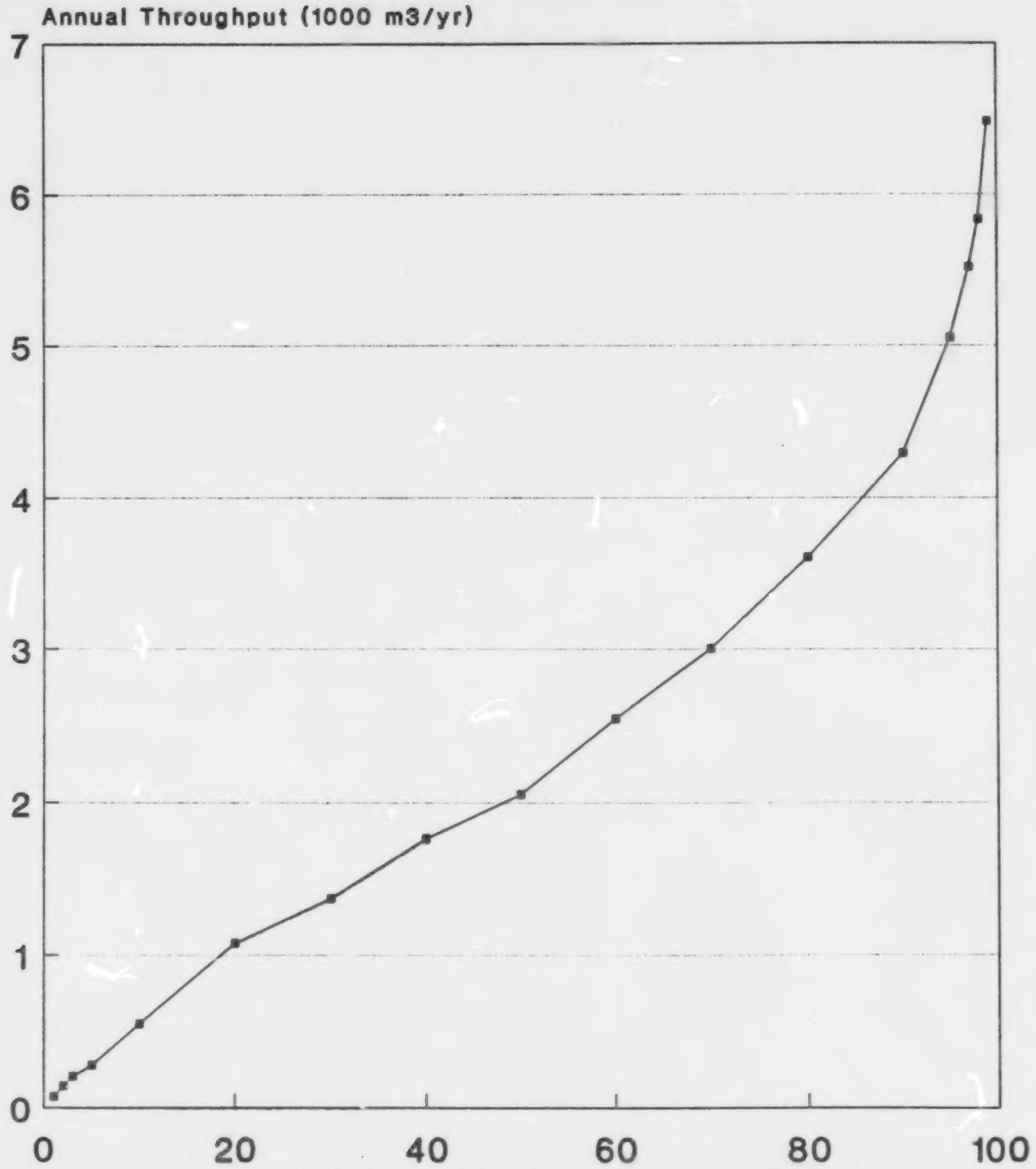


FIGURE III-1 DISTRIBUTION OF GASOLINE THROUGHPUT AT SERVICE STATIONS

area. The number of nozzles at these stations ranged from 1 to 20. Including all grades of gasoline, the average number of nozzles per station was found to be just over 8. Stations commonly had 8 or 12 nozzles, with this group accounting for 46% of the number of stations included in the survey. The frequency distribution for the service stations based on the number of nozzles for all gasoline grades is given in Figure III-2. The number of nozzles at a station could not be correlated with the annual gasoline throughput.

The frequency distribution for flows through nozzles by grade was determined for the 91 stations included in the survey. Results for sales of regular gasoline (Figure III-3) show that an average 338 m^3 is dispensed per nozzle. The quantity dispensed per nozzle for premium gasoline is somewhat lower, being 175 m^3/nozzle when stations reporting zero sales are ignored (Figure III-4). The throughput for nozzles dispensing unleaded gasoline is 343 m^3/nozzle when stations having zero sales are ignored (Figure III-5). This rate is similar to that for sales of regular gasoline. The average throughput for all grades of gasoline is 296 m^3/nozzle.

The annual throughput per station for the 91 stations included in the survey and the associated range of the number of nozzles is given in Table III-5. There is no direct correlation between the station throughput and the number of nozzles.

The number of islands at the 91 stations surveyed varied between 1 and 7, with 2 islands being the most common configuration. These stations account for over 50% of the ones surveyed as shown in Figure III-6. The bulk of the remainder was equally distributed between 1 and 3 islands per station. No correlation existed between the number of islands and the throughput.

B. Design Specifications for Control Options

1. Procedure for Finalizing the Design Specifications

Design specifications were developed for each of the control options identified in the previous chapter to allow estimates of capital and operating costs to be made for control options appropriate to local circumstances. A two-stage approach was used to arrive at the design specifications. First, preliminary design specifications and key assumptions were developed from discussions with equipment suppliers and by extracting pertinent information from the emissions inventory data base prepared in the previous study. The resulting preliminary specifications were circulated to personnel in Chevron, Esso, Petro Canada and Shell with the cooperation of

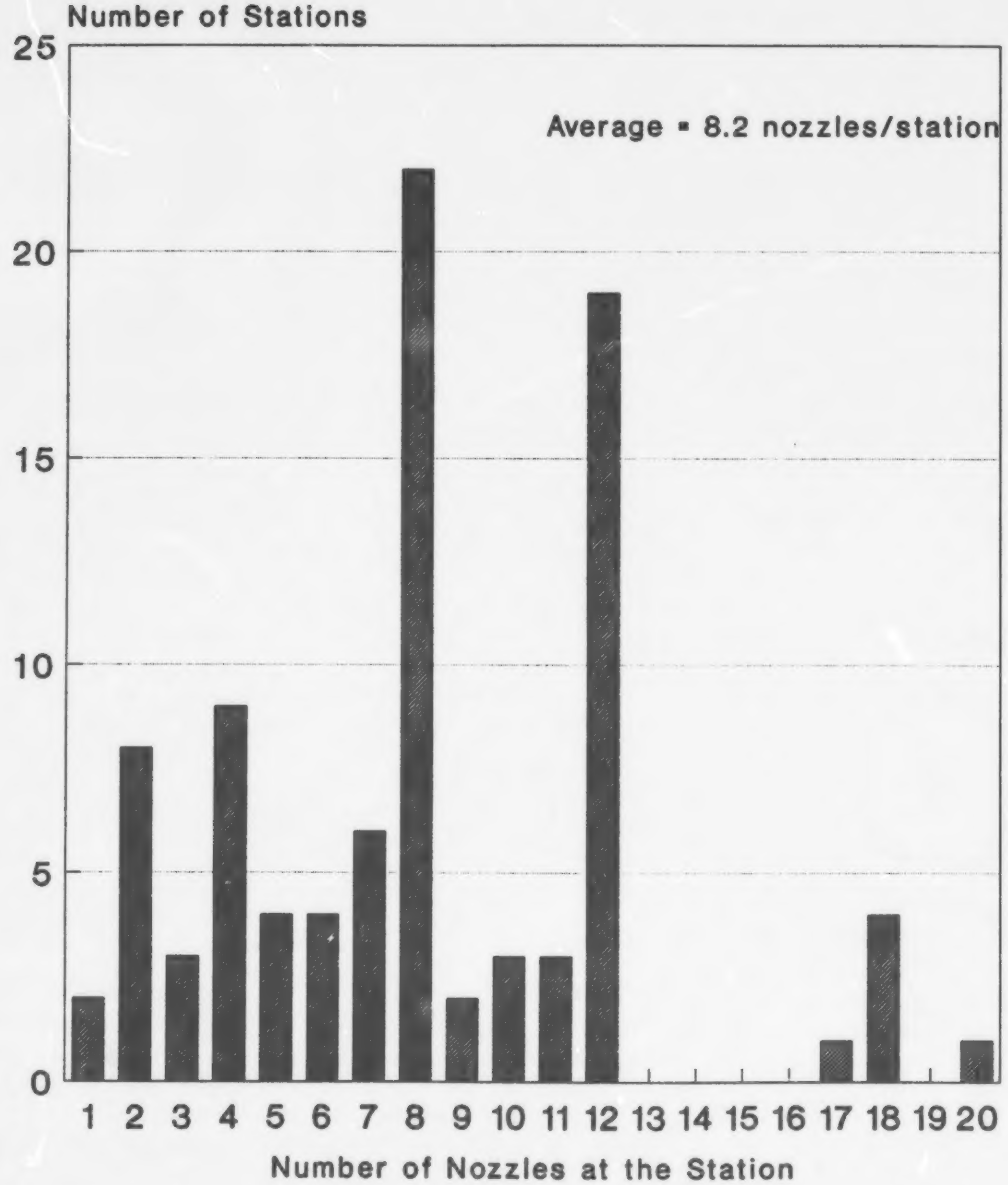


FIGURE III-2 FREQUENCY DISTRIBUTION FOR THE NUMBER OF NOZZLES AT 91 STATIONS IN THE STUDY AREA

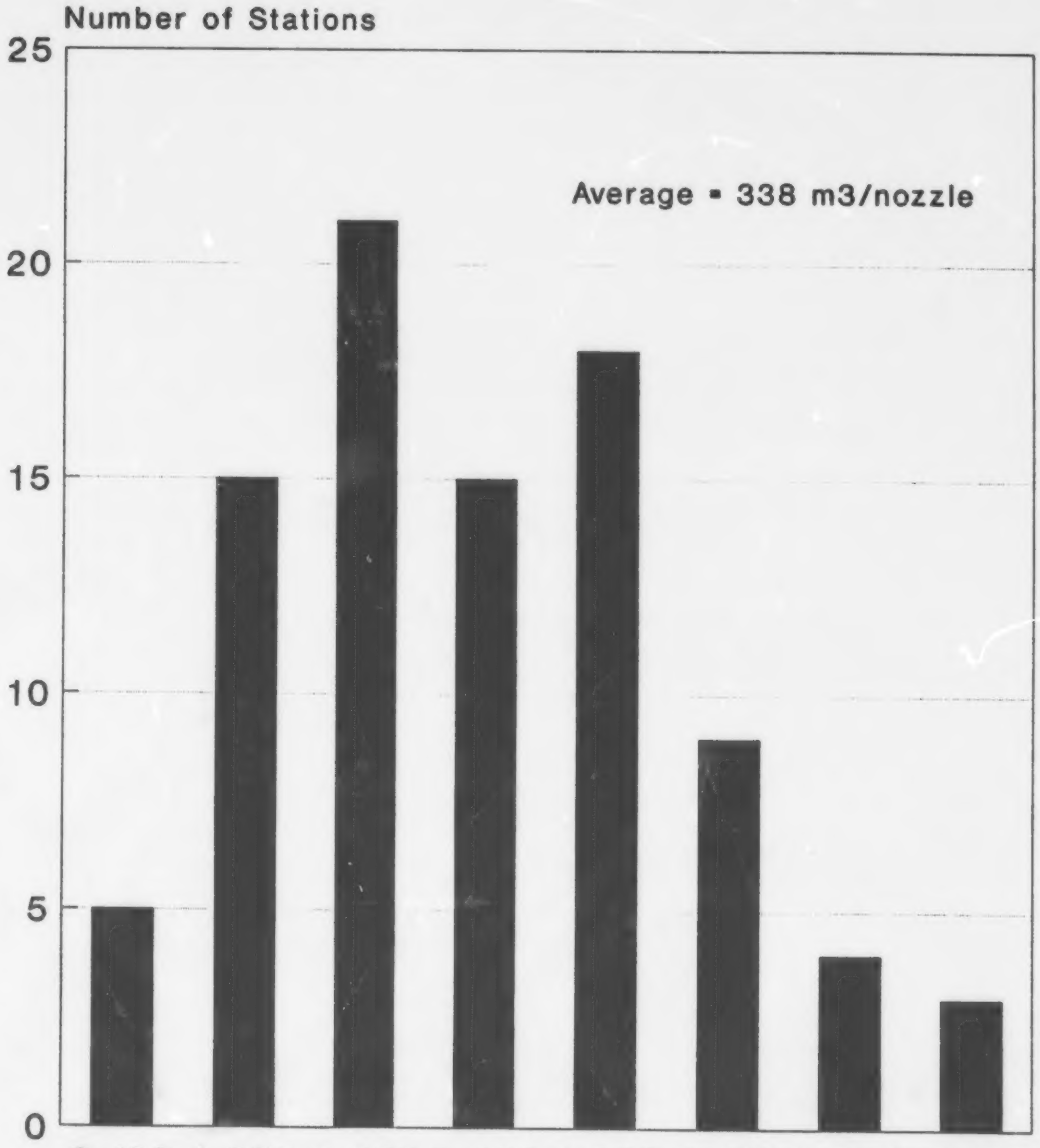


FIGURE III-3 THROUGHPUT PER NOZZLE FOR REGULAR GASOLINE

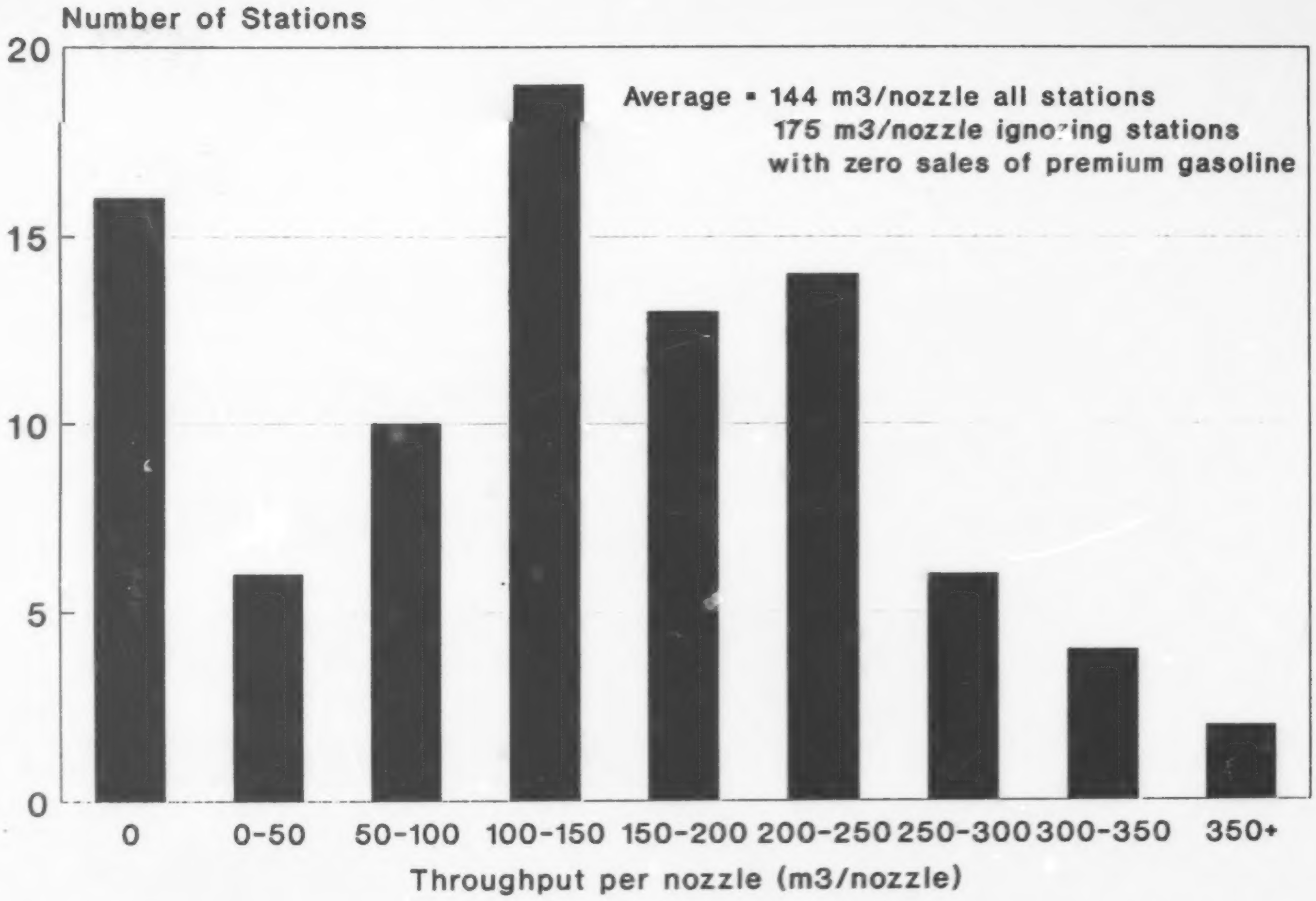


FIGURE III-4 THROUGHPUT PER NOZZLE FOR PREMIUM GASOLINE

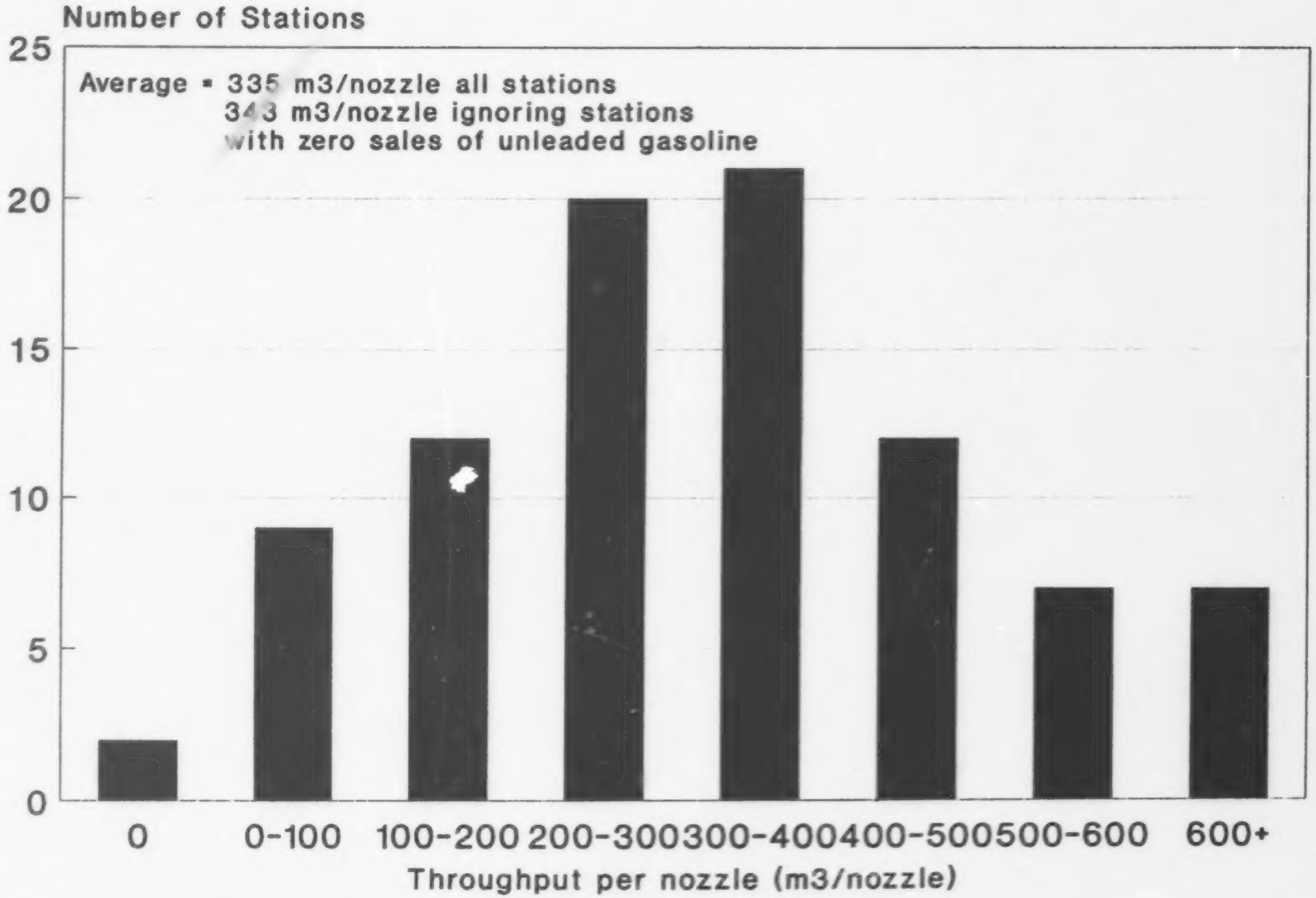


FIGURE III-5 THROUGHPUT PER NOZZLE FOR UNLEADED GASOLINE

TABLE III-5 DISTRIBUTION OF THROUGHPUT BY NUMBER OF NOZZLES

RANGE OF NOZZLES	ANNUAL THROUGHPUT (m^3/yr)
< 8	Less than 2300 (linear)
8 - 12	2000 - 4500
> 12	More than 4000

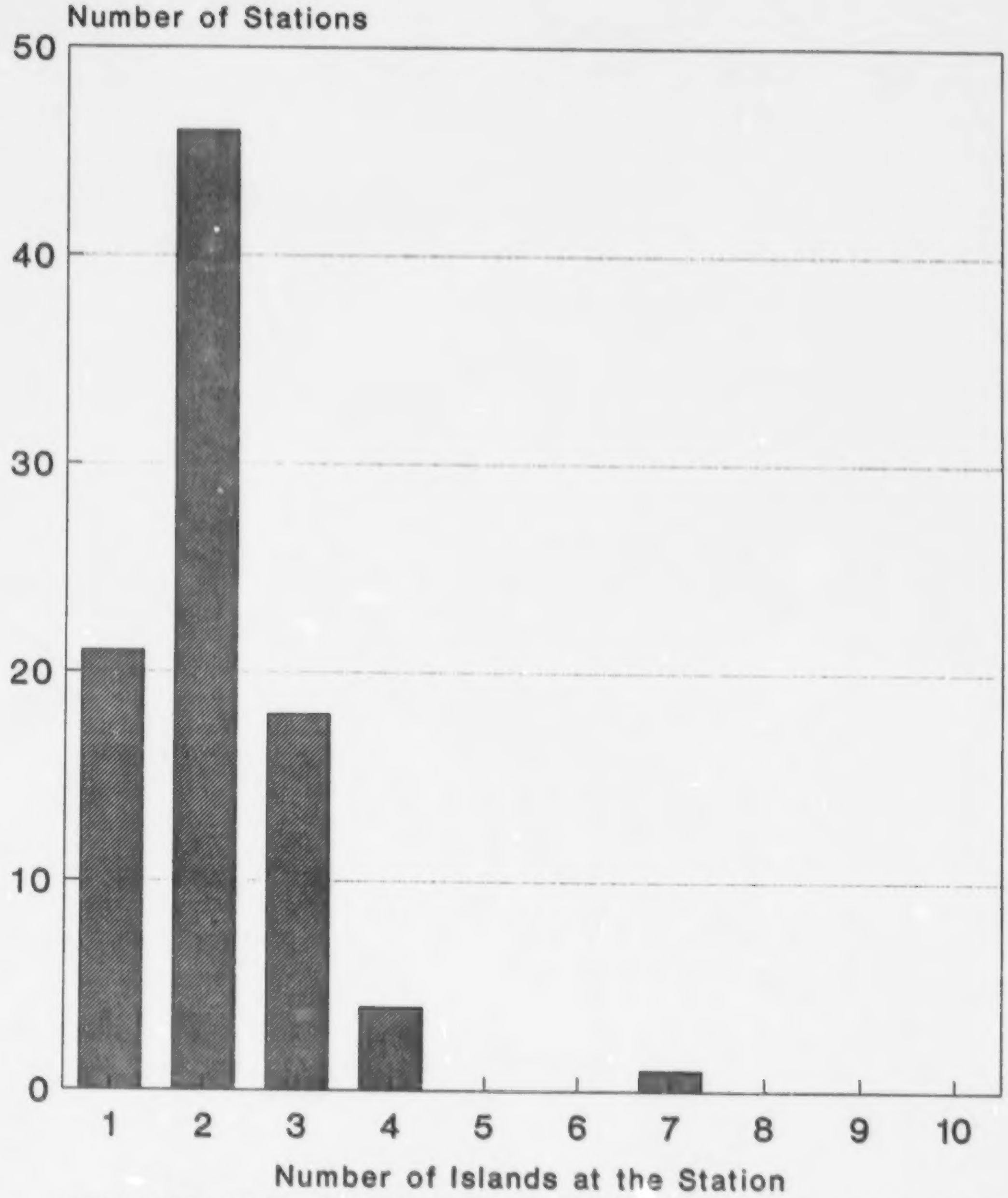


FIGURE III-6 NUMBER OF ISLANDS AT 91 SERVICE STATIONS IN THE STUDY AREA

the B.C. Petroleum Association. Comments were received from these contacts, which were used to finalize the design specifications. Industry reviewed the design specifications and concurred with using these as the basis for selecting the control options and deriving the cost estimates. It is important to realize, however, that the review of the preliminary design specifications done by industry representatives did not involve rigorous analysis of their company's sources and assembly of design data. Rather, it involved a general consideration of the specifications by those experienced with the sources being considered. Discussions were held with all industry representatives who participated in the review process to ensure a clear understanding of the vagaries of the sources was obtained.

2. Design Specifications

(a) Fixed Roof Tanks

The fixed roof tanks located at the refineries, terminals and bulk plants fall into three categories according to the types of VOC control that apply.

(i) Large Fixed Roof Tanks

Working loss VOC emissions from large fixed roof tanks with storage capacities of 150 m^3 or more and with gasoline throughputs resulting in more than ten (10) tank turnovers per year can be controlled by retrofitting to internal floating roof tanks. In the study area gasoline marketing network there are four tanks, all located at bulk terminals, which fall into this category.

One typical tank has been selected as a case study. The specifications for this tank are in Table III-6.

For the purposes of retrofitting it is assumed that the tank has typical accessories such as a pressure/vacuum vent, a gauge hatch, a manhole and a ladder. Furthermore, it is assumed that the tank is round and in good structural condition.

(ii) Small Fixed Roof Tanks

VOC emissions from small fixed roof tanks with storage capacities less than 150 m^3 can be controlled by vapour balancing. In the Lower Mainland gasoline marketing network these smaller tanks are

TABLE III-6 FIXED ROOF TANK SPECIFICATIONS

Diameter	18.3 m
Height	12.2 m
Capacity	3200 m^3
Number of columns	3 (assumed)
Annual throughput	128,000 m^3
Tank turnovers	40
Colour	White
Product	Unleaded

located primarily at bulk plants. Small fixed roof tanks located at refineries or terminals will not be considered because it is often impractical to apply vapour balancing or other methods to these tanks. Furthermore, total emissions from these sources are insignificant, accounting for only 0.5% of total VOC emissions from gasoline marketing.

One typical bulk plant has been selected as being representative of the 15 bulk plants with above ground fixed roof tanks in the Lower Mainland. Specifications for this plant are in Table III-7.

For the purposes of retrofitting the bulk plant for vapour balancing it is assumed that all tanks have a manhole and a 4" vent on the roof and that the tanks are in a straight row.

(iii) Other Fixed Roof Tanks

Fixed roof tanks with storage capacities in excess of 150 m^3 but with throughputs resulting in less than 10 tank turnovers per year are not considered for VOC emission control for the following reasons:

- these tanks store aviation gasoline, a low volatility product;
- total VOC emissions from this source are insignificant (0.5%).

(b) Bulk Transfer of Gasoline

The bulk transfer of gasoline is either by truck at four bulk terminals or by ship and barge at four marine terminals located at or near the refineries.

(i) Truck Transfers at Bulk Terminals

VOC emissions from the bulk transfer of gasoline at truck loading terminals can be controlled by collecting the vapours displaced during the filling of tank trucks and passing the vapours to a vapour processing unit. The technology available for processing the vapours will be discussed in Section IV.

TABLE III-7 BULK PLANT SPECIFICATIONS

Number of tanks storing gasoline	3	
Diameter	3.2 m	
Height	5.6 m	
Volume	45 m^3	3 tanks - 135 m^3
Annual throughput	5422 m^3	
Average number of tank turnovers	40	
Colour	Aluminum	
Products	Regular, regular unleaded	
Spacing (wall to wall)	1.2 m	
Distance from unloading bay	10 m	
Pumping rate	1000 L/min (assumed)	

The four terminals located in the study area vary in annual throughputs, and loading capacities by a factor of about 1.5. Therefore, two generic cases will be evaluated which are representative of a "low" and "high" throughput terminal. Specifications for the two generic cases are presented in Table III-8. Typical and CGSB gasoline specifications and ambient conditions are listed in Table III-9.

For the purpose of retrofitting a bulk terminal for vapour control, numerous assumptions were made which have been confirmed by industry:

- all trucks are bottom-loaded;
- the degree of "switch-loading" is typically less than 10%;
- all lines to go underground;
- no existing lines available for the vapour collection or gasoline supply/return;
- recovered gasoline can be returned to the regular gasoline tank for other tanks already located in the same vicinity;
- only the bays with gasoline loading facilities will be covered by the vapour collection system;
- trucks are equipped with pressure/vacuum vents.

(ii) Ship and Barge Transfers at Marine Terminals

VOC emissions from the bulk transfer of gasoline at marine loading terminals can be controlled by collecting the vapours displaced during the filling of marine vessels and passing the vapours to a central processing unit. The technology for control of VOC emissions at marine terminals is similar to the technology applied to truck terminals. VOC control at marine terminals is not presently as widespread as truck terminal VOC control.

The four marine terminals located in the study area vary in annual throughput by a factor of 3 and in loading capacities by a factor of 1.5.

TABLE III-8 TRUCK TERMINAL SPECIFICATIONS

	"LOW" THROUGHPUT	"HIGH" THROUGHPUT
Processing Unit:		
Instantaneous loading rate	6,400 L/min	9,000 L/min
Peak 15 minute period throughput	95,000 L	135,000 L
Peak 1 hour period throughput	210,000 L	420,000 L
Peak 24 hour period throughput	1,400,000 L	2,000,000 L
Installation and Piping:		
Gasoline loading bays	3	3
Vapour piping length (main arm)	80 m	80 m
Gasoline supply/return line length (if required)	150 m	150 m
Trucks	15	20
Average truck tank capacity	42,500 L	45,000 L
Number of compartments:		
(per truck)) A, B trains	4	4
(per pup))	2	2
Semi	5	5

TABLE III-9 TYPICAL AND CGSB GASOLINE SPECIFICATIONS AND AMBIENT CONDITIONS

	Typical	CGSB	
Reid Vapour Pressure:			
Summer	76 kPa max	79 kPa max	
Winter	104 kPa max	69 kPa min	107 kPa max
Temperature:			
Summer	29°C		
Winter	0°C		
VOC Vapour Concentration (from loading rack)	20 - 40 % by volume in collected vapour		

Therefore, two generic cases will be evaluated which are representative of low and high loading rate terminals. Specifications for the two generic cases are presented in Table III-10. Gasoline specifications and ambient conditions are listed in Table III-9.

For the purpose of retrofitting a marine terminal for vapour control, numerous assumptions have been made. Industry has confirmed loading rates and typical piping distances.

- all vessels are filled via solid pipe connections;
- all tanks on the vessels are equipped with pressure/vacuum vents, manholes and site gauges;
- land is available for the vapour processing unit;
- gas and electricity is available within 1 km.

(c) Service Stations

Service stations located throughout the study area vary in equipment and throughput. There are no trends relating throughput to nozzles or islands. Furthermore, there is no typical throughput. Therefore, two design specifications were developed for a medium and a large station that are illustrative of the existing service station population. Specifications for these stations are listed in Table III-11.

For the purpose of retrofitting stations for vapour balancing numerous assumptions were made which industry has verified:

- individual vapour collection lines are not necessary, manifolded collection will suffice;
- no existing lines or equipment for vapour balance exist;
- all tanks are vented;

Other assumptions were made for the two stations based on visits to local service stations:

TABLE III-10 MARINE TERMINAL SPECIFICATIONS

	"LOW" LOADING RATE	"HIGH" LOADING RATE
Instantaneous loading rate	10,000 L/min	16,000 L/min
Peak 15 minute throughput	150,000 L	240,000 L
Peak 1 hour throughput	600,000 L	960,000 L
Peak 24 hour throughput	14,400,000 L	23,000,000 L
Loading positions	2	3
Vapour piping length	100 m	100 m
Gasoline supply/return line length	200 m	200 m
Barges/ships	5	5
Tank capacities	2700 - 56,000 m^3	2700 - 56,000 m^3

TABLE III-11 SERVICE STATION SPECIFICATIONS

	THROUGHPUT	
	2000 m^3/yr	4000 m^3/yr
Case I:		
Nozzles	8	12
Islands	2	2
Tanks	3	3
Case II:		
Nozzles	12	16
Islands	3	3
Tanks	3	3

- multiproduct dispensers were not in widespread use;
- typical hose lengths were up to 4 m;
- typical layouts are in Figure III-7 a,b;
- tanks are typically 20000 - 25000 L in size (2 m diameter x 8 m long);
- tanks are 1.2 m deep and 0.6 m apart;
- separate trenches for liquid and vapour lines are required.

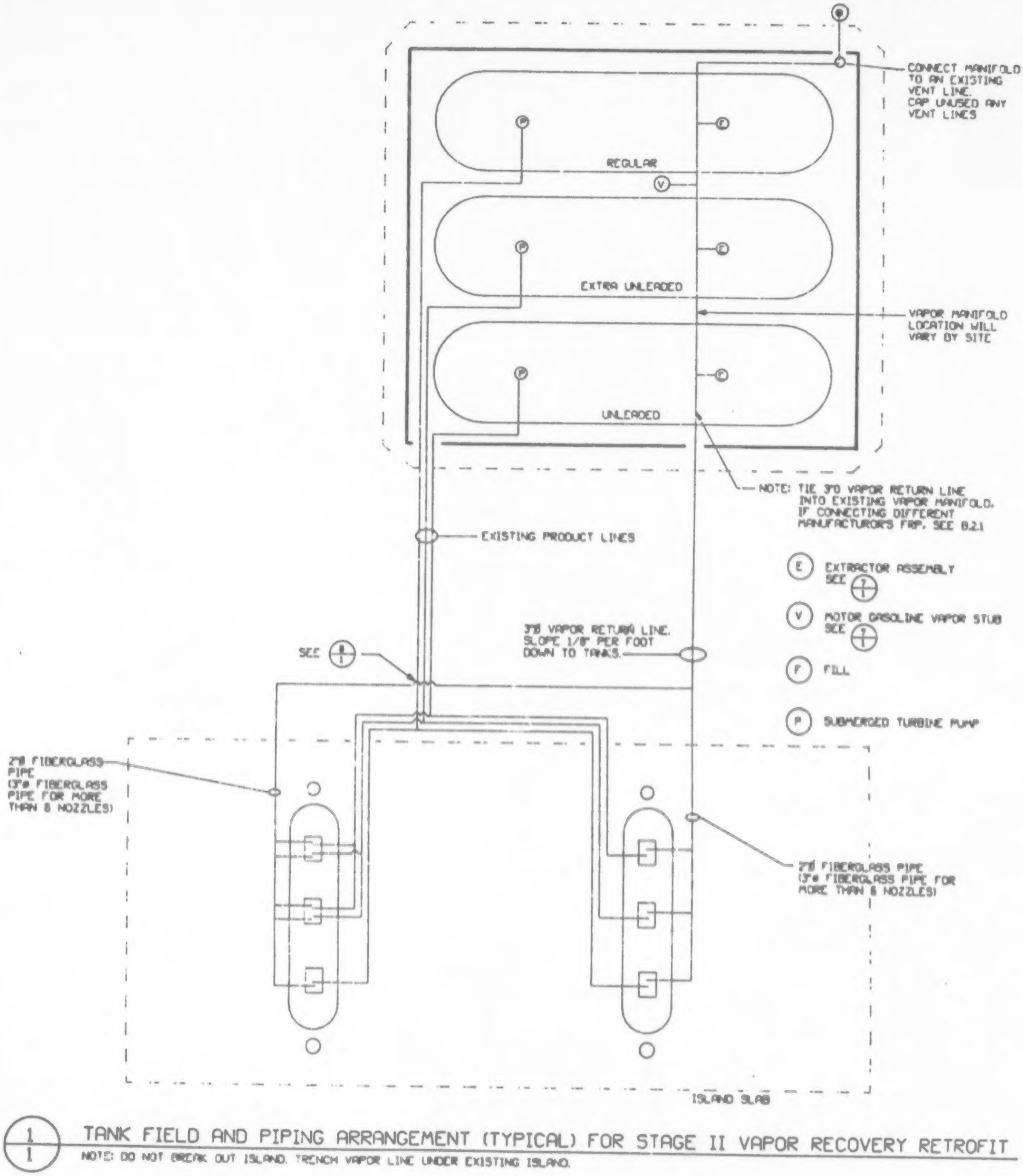

CONNECT MANIFOLD TO AN EXISTING VENT LINE. CAP UNUSED ANY VENT LINES
P
E
REGULAR
V
EXTRA UNLEADED
VAPOR MANIFOLD LOCATION WILL VARY BY SITE
UNLEADED
NOTE: TIE 3"Ø VAPOR RETURN LINE INTO EXISTING VAPOR MANIFOLD. IF CONNECTING DIFFERENT MANUFACTUROR'S FRP, SEE B.2.1
EXISTING PRODUCT LINES
E EXTRACTOR ASSEMBLY SEE 7/1
V MOTOR GASOLINE VAPOR STUB SEE 7/1
F FILL
P SUBMERGED TURBINE PUMP
3"Ø VAPOR RETURN LINE. SLOPE 1/8" PER FOOT DOWN TO TANKS.
SEE 8/1
2"Ø FIBERGLASS PIPE (3"Ø FIBERGLASS PIPE FOR MORE THAN 8 NOZZLES)
2"Ø FIBERGLASS PIPE (3"Ø FIBERGLASS PIPE FOR MORE THAN 8 NOZZLES)
ISLAND SLAB
1/1
TANK FIELD AND PIPING ARRANGEMENT (TYPICAL) FOR STAGE II VAPOR RECOVERY RETROFIT
NOTE: DO NOT BREAK OUT ISLAND. TRENCH VAPOR LINE UNDER EXISTING ISLAND.

FIGURE III-7 TANK FIELD AND PIPING ARRANGEMENT (TYPICAL) FOR STAGE II VAPOUR RECOVERY RETROFIT

Scale: 1 cm = 2 m

IV. EVALUATION OF EMISSION CONTROL SYSTEMS

A. Gasoline Storage Tanks

1. Retrofitting Fixed Roof Tanks with Internal Floating Roofs

Retrofitting of fixed roof tanks by adding a floating deck is recommended by the US EPA's Burr et al (1977) as readily available control technology for tanks over 150 m^3 in capacity. This only applies to fixed roof tanks at the terminals and refineries in this study area. An internal floating roof tank is shown in Figure IV-1.

Decks can be made of different materials such as steel, aluminum or polyurethane. The choice of material affects cost and deck life. Some typical deck types and seals are shown in Figure IV-2.

Prior to installing a floating roof, some adjustments may be necessary such as:

- correcting any shell deformaties or obstructions;
- modifying the tank structure by bracing or reinforcing;
- replumbing vertical support columns.

Other equipment which is necessary includes:

- anti-rotational guides;
- special vent valves to prevent VOC's in the vapour space underneath the deck from approaching the flammable range.

Tanks must be drained, cleaned and vented and possibly de-leaded prior to installing the deck (floating roof). After the roof is assembled inside the tank, it must be carefully floated up to prevent the vapours from entering the explosive limit.

Emissions from fixed roof and internal floating roof tanks vary with tank diameter and components, wind speed, temperature and throughput but typical reductions of 90% or more can be expected according to Burr et al (1977). Based on the emission factors used in this study and a comparison with internal floating roof tanks of the same size and with the same throughputs as the four tanks in this study, emission reductions of 98% could be expected.

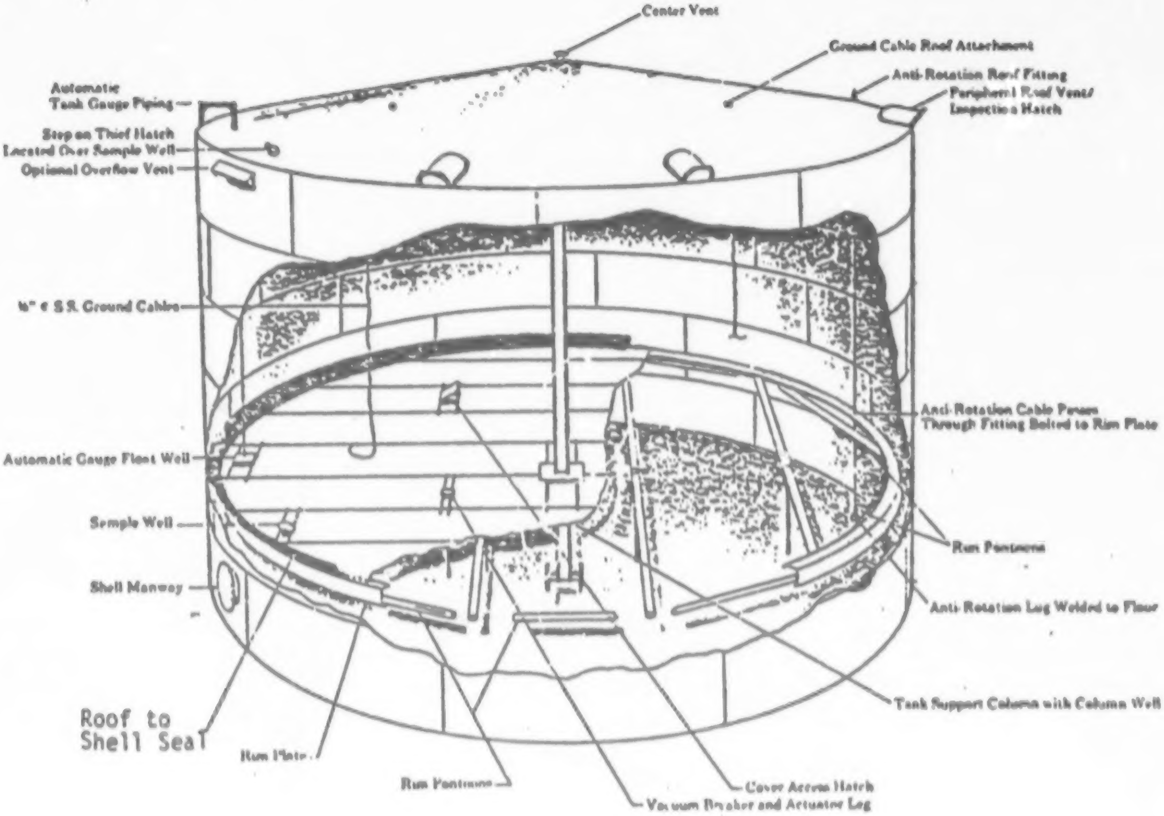
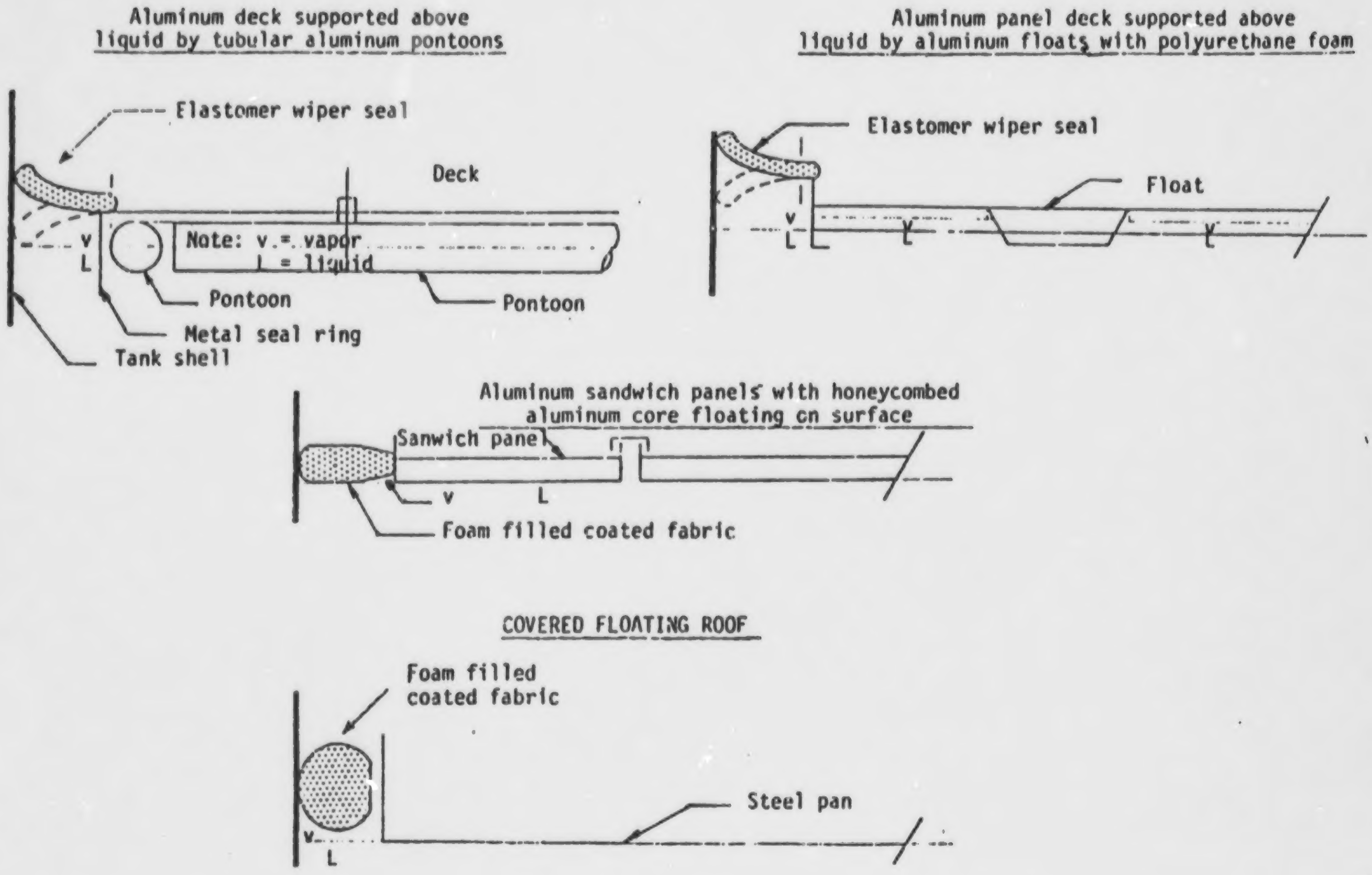

Center Vent
Ground Cable Roof Attachment
Anti-Rotation Roof Fitting
Peripheral Roof Vent/
Inspection Hatch
Automatic
Tank Gauge Piping
Step on Thief Hatch
Located Over Sample Well
Optional Overflow Vent
¼" ∅ S.S. Ground Cable
Anti-Rotation Cable Passes
Through Fitting Bolted to Rim Plate
Automatic Gauge Float Well
Sample Well
Rim Pontoons
Shell Manway
Anti-Rotation Lug Welded to Floor
Tank Support Column with Column Well
Roof to
Shell Seal
Rim Plate
Rim Pontoons
Cover Access Hatch
Vacuum Breaker and Actuator Leg

FIGURE IV-1 SCHEMATIC OF TYPICAL FIXED ROOF TANK WITH INTERNAL FLOATING COVER

Source: Burr et al (1977)



Aluminum deck supported above liquid by tubular aluminum pontoons

Aluminum panel deck supported above liquid by aluminum floats with polyurethane foam

Aluminum sandwich panels with honeycombed aluminum core floating on surface

COVERED FLOATING ROOF

Elastomer wiper seal
Deck
Note: v = vapor
L = liquid
v
L
Pontoon
Pontoon
Metal seal ring
Tank shell
Elastomer wiper seal
Float
v
L
L
L
Sanwich panel
v
L
Foam filled coated fabric
Foam filled
coated fabric
Steel pan
v
L

FIGURE IV-2 TYPICAL FLOTATION DEVICES AND PERIMETER SEALS FOR INTERNAL FLOATING COVERS, AND COVERED FLOATING ROOF

Source: Burr et al (1977)

Internal floating roof retrofitting as a standard type of technology for the control of working loss emissions is often undertaken by owners to reduce the loss of petroleum liquids. In other words, the value of the liquids which would have been lost may pay out the cost of installing the floating roof. Maintenance is minimal, requiring only semi-annual visual inspection of the cover and seal for holes.

2. Retrofitting External Floating Roof Tanks with Secondary Seals

An external floating roof tank is shown in Figure IV-3. Primary seals are in use in the study area so secondary seals could be added to reduce emissions. Some typical primary seals are shown in Figure IV-4. Rim-mounted secondary seals tend to be more effective than shoe-mounted secondary seals in reducing VOC emissions. Figure IV-5 shows some of the rim-mounted secondary seals available.

Operational problems are minimal. Routine visual inspections done semi-annually would be sufficient. Emission reductions would be in the order of 80 - 90% based on calculations of standing losses using AP-42 factors for primary and secondary seals. Burr et al (1978) in a US EPA document reports emission reductions in the order of 50 - 60%. The difference between our estimates and Burr's results because of the different seal type or configuration, throughput, wind speed, temperature and other factors.

3. Vapour Balance for Smaller Fixed Roof Tanks at Bulk Plants

Installation of vapour balance systems for fixed roof tanks at bulk plants requires piping to return the vapour to the fuel source. The head space of all gasoline tanks are connected, usually in a manifold system with assorted valves and pressure/ vacuum vents. The manifold is connected via a temporary flexible hose to the delivery truck tank vapour space.

There are many factors which can affect the efficiency of vapour recovery when using vapour balance technology. The integrity of the system can be improved by:

- preventing liquid leakage through cracked seals or improper connections or careless hook-ups of lines, etc;
- preventing over-fill caused by fill meter errors, shut-off valve failures, etc.;
- ensuring that pressure-vacuum relief valves are operating and set properly.

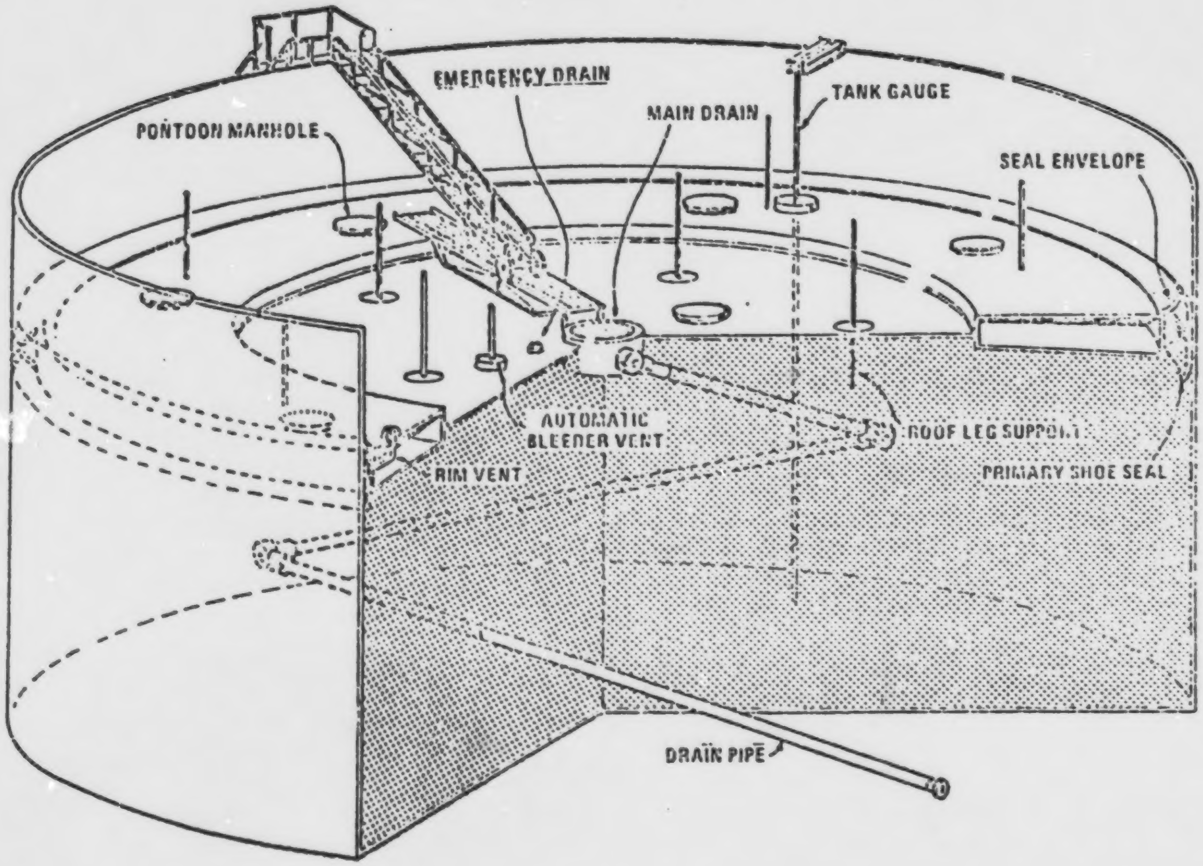
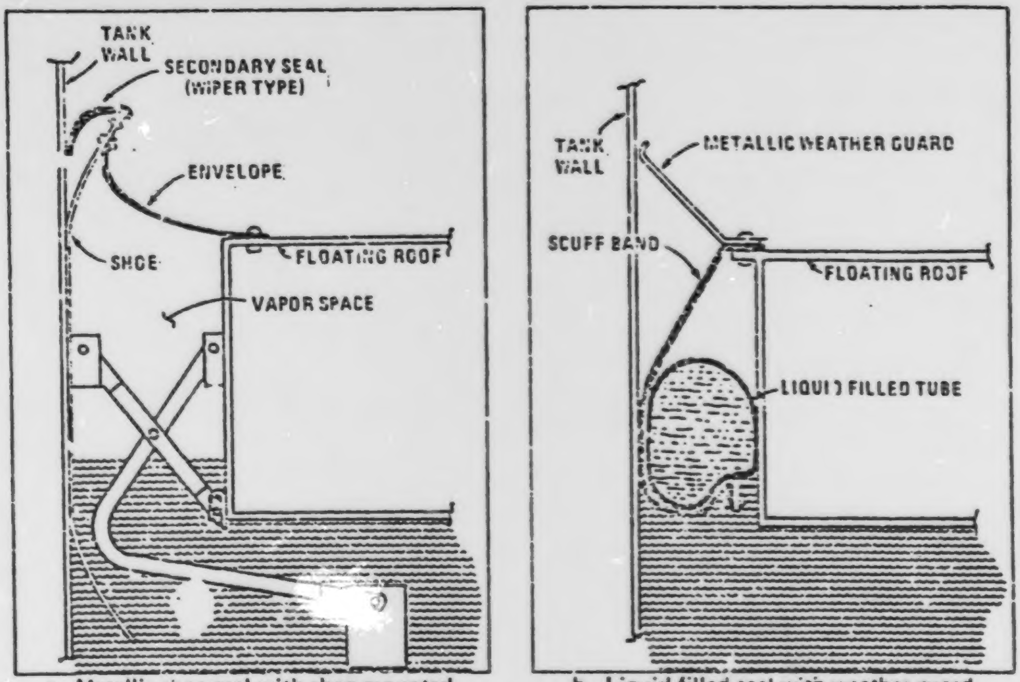

EMERGENCY DRAIN
TANK GAUGE
MAIN DRAIN
PONTOON MANHOLE
SEAL ENVELOPE
AUTOMATIC BLEEDER VENT
ROOF LEG SUPPORT
RIM VENT
PRIMARY SHOE SEAL
DRAIN PIPE

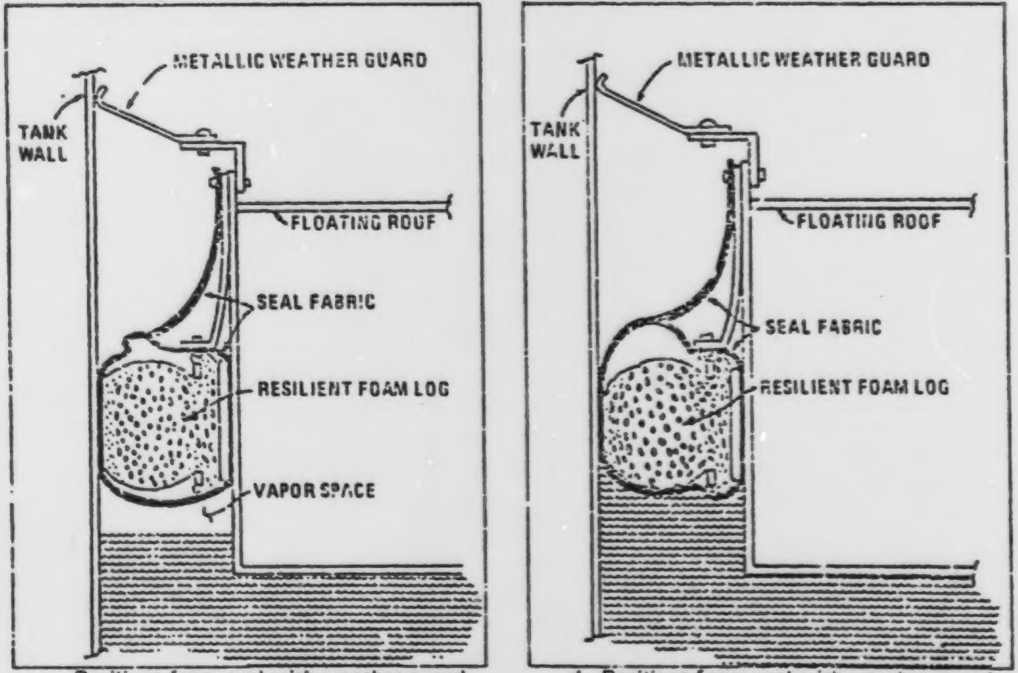
FIGURE IV-3 EXTERNAL FLOATING ROOF TANK (PONTOON TYPE)

Source: Burr et al (1978)


TANK WALL
SECONDARY SEAL (WIPER TYPE)
ENVELOPE
SHOE
FLOATING ROOF
VAPOR SPACE
TANK WALL
METALLIC WEATHER GUARD
SCUFF BAND
FLOATING ROOF
LIQUID FILLED TUBE

a. Metallic shoe seal with shoe-mounted secondary.

b. Liquid-filled seal with weather guard.

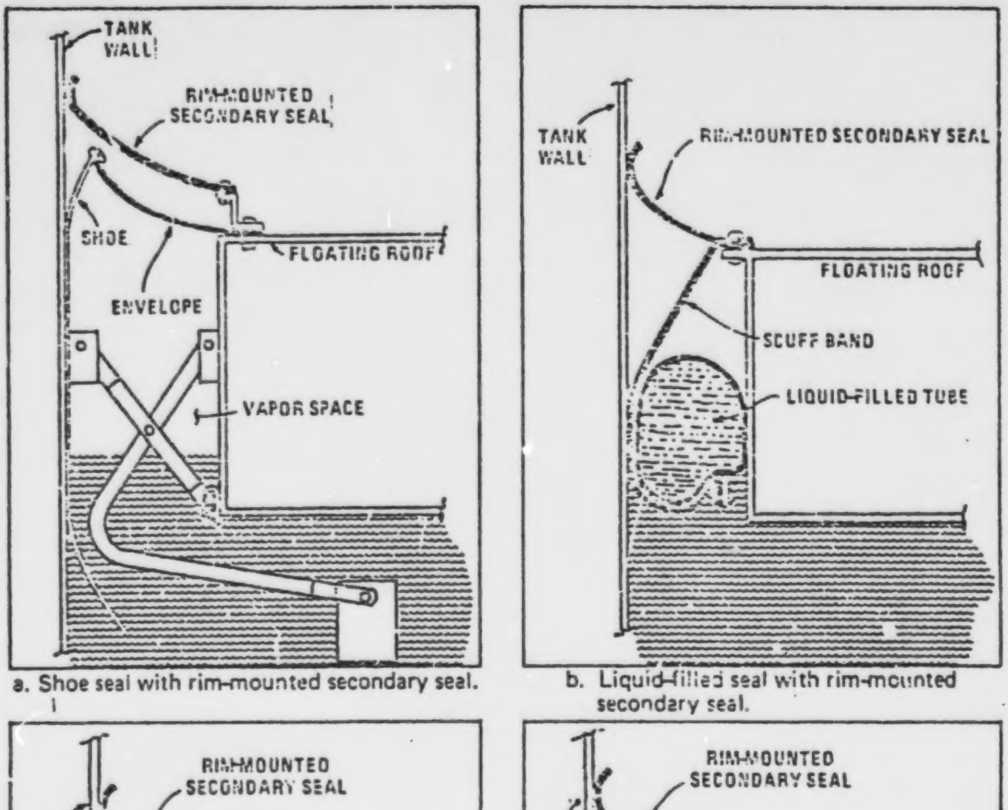

METALLIC WEATHER GUARD
TANK WALL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM LOG
VAPOR SPACE
METALLIC WEATHER GUARD
TANK WALL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM LOG

c. Resilient foam seal with weather guard (vapor-mounted).

d. Resilient foam seal with weather guard (liquid-mounted).

FIGURE IV-4 PRIMARY SEALS FOR FLOATING ROOFS

Source: Burr et al (1978)


TANK WALL
RIM-MOUNTED SECONDARY SEAL
SHOE
ENVELOPE
FLOATING ROOF
VAPOR SPACE
TANK WALL
RIM-MOUNTED SECONDARY SEAL
FLOATING ROOF
SCUFF BAND
LIQUID-FILLED TUBE
TANK WALL
RIM-MOUNTED SECONDARY SEAL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM LOG
VAPOR SPACE
TANK WALL
RIM-MOUNTED SECONDARY SEAL
FLOATING ROOF
SEAL FABRIC
RESILIENT FOAM LOG

a. Shoe seal with rim-mounted secondary seal.

b. Liquid-filled seal with rim-mounted secondary seal.

c. Resilient foam seal (vapor-mounted) with rim-mounted secondary

d. Resilient foam seal (liquid-mounted) with rim-mounted secondary seal

FIGURE IV-5 RIM-MOUNTED SECONDARY SEALS FOR FLOATING ROOF

Source: Burr et al (1978)

Regular maintenance is essential to minimize leaks in a balance system.

Figure IV-6 illustrates the vapour balance systems for a bulk plant where submerged loading of trucks is used. Emissions of VOCs are reduced by 40% from the uncontrolled case because of the reduction in tank working loss (Shedd and Efird, 1977).

Further vapour balancing between the storage tanks and the account trucks is also possible but is not considered practical for the following reasons:

- account trucks are usually top-submerged loaded requiring extensive modifications to the loading rack and account trucks;
- vapour collection lines would have to be routed underground;
- VOC emissions from this source are very small (58.5 tonnes/yr or less than 1% of the total emissions from gasoline marketing).

Consequently, emissions from loading of account trucks remains uncontrolled in the overall control strategy.

B. Bulk Transfer of Gasoline

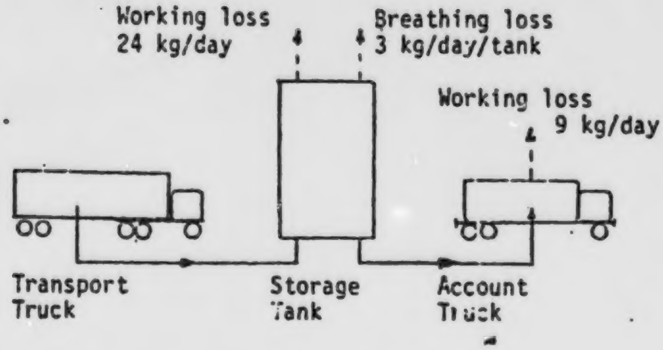
There are a number of different options available for controlling VOC emissions arising from the bulk loading of gasoline. They can be divided into two general categories:

- vapour recovery options;
- vapour destruction options systems.

A list of many of the different systems appears in Table IV-1. Due to economics, reliability, performance or safety, only three of these systems are in widespread use, namely: refrigeration, adsorption-absorption and thermal oxidation.

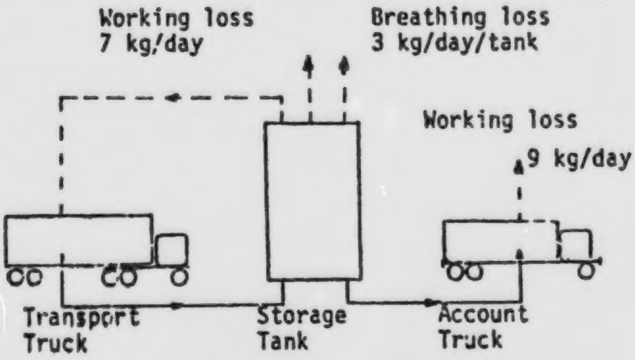
The cost of these systems dictates that they be located at central locations with high gasoline throughputs such as at bulk terminals and refineries.

A brief description of all systems listed in Table IV-1 follows with emphasis on the systems most widely used. Tables IV-2 and IV-3 are summaries of pertinent information for comparison purposes.


Working loss
24 kg/day
Breathing loss
3 kg/day/tank
Working loss
9 kg/day
Transport
Truck
Storage
Tank
Account
Truck

Total emissions: 42 kg/day

A. Uncontrolled


Working loss
7 kg/day
Breathing loss
3 kg/day/tank
Working loss
9 kg/day
Transport
Truck
Storage
Tank
Account
Truck

Total emissions: 25 kg/day

B. Controlled Using Vapour Balance

Basis: Throughput 15,000 L/day
3 storage tanks (each having emission shown)

FIGURE IV-6 TYPICAL VAPOUR BALANCE SYSTEM AT BULK PLANT

Source: Shedd and Efird (1977).

TABLE IV-1 VAPOUR CONTROL SYSTEMS

TYPE OF PROCESS
Vapour Recovery Processes
Compression-refrigeration-absorption
Compression-refrigeration-condensation
Lean-oil-absorption
Refrigeration
Adsorption-absorption
Vapour Destruction Processes
Thermal Oxidation

TABLE IV-2 COMPARISON OF VAPOUR CONTROL PROCESSES

SYSTEM	TYPICAL PEAK SINGLE UNIT WORKING CAPACITY (L/min)	TYPICAL ENERGY CONSUMPTION (kWh/m^3 throughput)	RECOVERY/ DESTRUCTION EFFICIENCY	DISCHARGE LIMITS
Refrigeration	3,000 - 18,000	0.25 - 0.40	> 90%	--
Adsorption-Absorption	< 6,000 - 16,000	0.16 - 0.2	99%	3000 ppm
Thermal Oxidation	< 7,000 - 140,000	0.2 - 0.4 GJ/h	99+%	7 mg/L

TABLE IV-3 COMPARISON OF VAPOUR CONTROL SYSTEMS

	REFRIGERATION	CARBON ADSORPTION-ABSORPTION	THERMAL OXIDATION
Capital Cost	Highest	Middle	Lowest
Energy Costs	Higher	Lower	Higher
Product Recovery	Yes	Yes	No
Fire/Explosion Hazard	Very low	Moderate	Moderate
Calculation of Recovery/ Destruction Efficiency	Measured directly	Estimated	Estimated
Operation	Requires daily defrosting	Can shut down during operation lulls	Can shut down during operating lulls
Discharge emissions (mg/VOC/litre of throughput)	- 35	< 35	< 35

1. Compression-Refrigeration-Absorption (CRA) System

The CRA system is based on the absorption of vapours by chilled gasoline. The inlet vapours are saturated so that they are above the upper explosive limit (UEL). The vapours are then compressed and cooled prior to absorption. Absorption could be by two means:

- vapours contact chilled gasoline (-25°C) in a spray chamber;
- vapours bubble up a counter-current column contacting chilled (-1°C) gasoline baths.

Air is vented at the top of the absorber and liquid gasoline from the bottom is returned to storage.

CRA systems are dependent on inlet hydrocarbon concentration. Removal efficiency increases with increased concentration.

Discharge concentrations of 2 - 3% by volume or 60 to 80 mg/L of throughput are achievable with properly sized and operated CRA systems according to Cha et al (1979).

2. Compression-Refrigeration-Condensation (CRC Systems)

The CRC system was the first to be used by the petroleum industry for controlling VOC emissions. This system is basically a condensation process where inlet vapours are first saturated above the UEL and then compressed in a two-cycle compressor equipped with an inter-stage heat exchanger (intercooler). Compressed vapours are sent to a condenser. The condensed liquid along with condensate from the intercooler are sent back to storage. Vapours are vented from the top of the condenser.

Removal efficiency is improved with increased inlet hydrocarbon concentration. Properly sized and operated units can achieve discharge limits of 3% by volume or 80 mg/L according to Cha et al (1979).

Both the CRC and CRA systems suffered a variety of operational problems. The most common were compressor bearing failure and freezing according to Cha et al (1979).

3. Lean-Oil Absorption (LOA) Vapour Recovery System

The LOA system absorbs gasoline vapours into lean gasoline or oil in a packed column operated at atmospheric temperature and pressure.

The effectiveness of the LOA system depends on the liquid-to-vapour ratio in the absorber. This system could achieve discharge concentrations of 3% by volume or 80 mg/L according to Cha et al (1979).

One apparent drawback of the system is the need to generate lean gasoline or oil. This is done by heating the gasoline or oil to drive off the vapours. These vapours are then condensed and returned to storage. The lean gasoline or oil is then chilled and returned to a separate storage tank for use as an absorbent.

4. Adsorption-Absorption

There are two major suppliers of this equipment to the U.S. market - John Zink Company and McGill Americas, Inc. These processes are available in a variety of standard or custom sized units which adequately cover the range of applications within the study area. Both processes are very similar and are shown schematically in Figures IV-7 and IV-8.

Briefly, they operate as follows:

- vapour collected from trucks during the loading operation passes to an underground knock-out tank where condensate is removed;
- the vapour then enters through the bottom of one of two carbon beds where the hydrocarbon is adsorbed as it flows through the carbon bed;
- purified air vents to atmosphere (the only path to atmosphere) through the top vent on the adsorption beds;
- the second carbon bed is simultaneously stripped of adsorbed hydrocarbon by applying a vacuum followed by a high vacuum air purge;
- the vacuum discharge proceeds to a separator-absorber;
- the non-condensed vapours and air mixture rise up through a packed absorber where hydrocarbons are preferentially absorbed by liquid hydrocarbon (gasoline) from storage which cascades downward through the absorber;

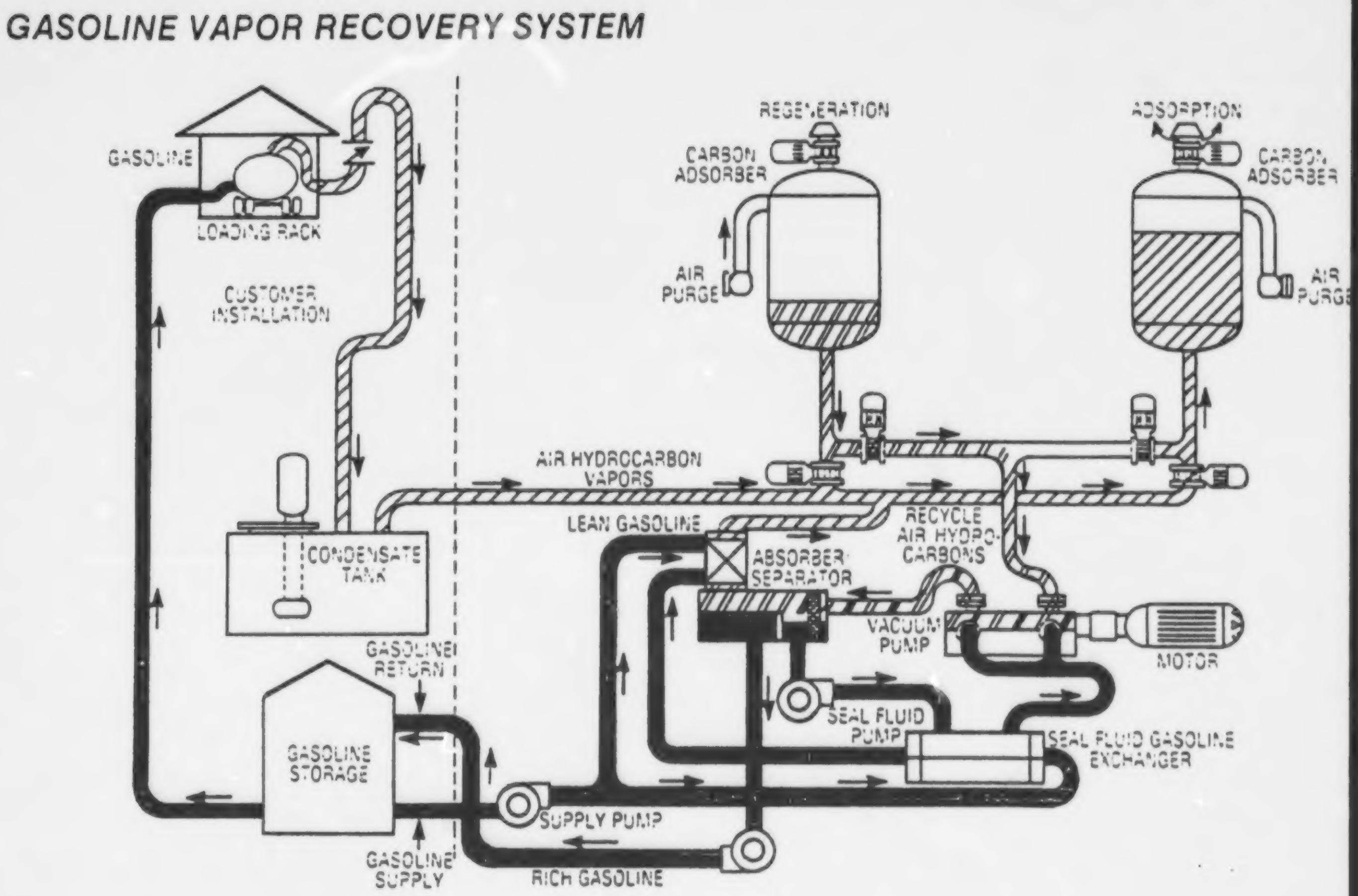

GASOLINE VAPOR RECOVERY SYSTEM
GASOLINE
LOADING RACK
CUSTOMER INSTALLATION
REGENERATION
CARBON ADSORBER
AIR PURGE
ADSORPTION
CARBON ADSORBER
AIR PURGE
AIR HYDROCARBON VAPORS
LEAN GASOLINE
RECYCLE AIR HYDRO-CARBONS
CONDENSATE TANK
ABSORBER SEPARATOR
VACUUM PUMP
MOTOR
GASOLINE RETURN
SEAL FLUID PUMP
SEAL FLUID GASOLINE EXCHANGER
GASOLINE STORAGE
SUPPLY PUMP
GASOLINE SUPPLY
RICH GASOLINE

FIGURE IV-7 SCHEMATIC OF ADSORPTION-ABSORPTION VAPOUR CONTROL SYSTEM - ZINK

Source: John Zink Company

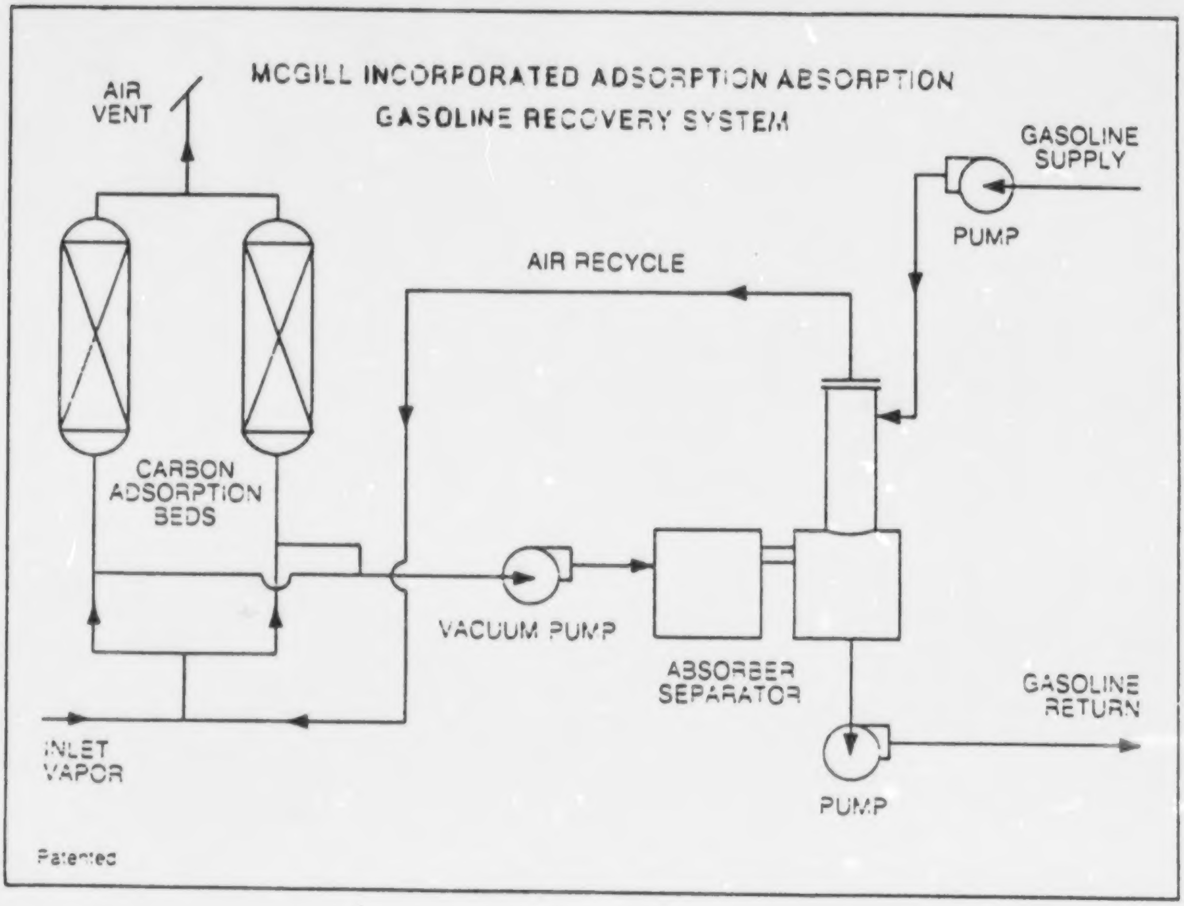

MCGILL INCORPORATED ADSORPTION ABSORPTION
GASOLINE RECOVERY SYSTEM
AIR VENT
GASOLINE SUPPLY
PUMP
AIR RECYCLE
CARBON ADSORPTION BEDS
VACUUM PUMP
ABSORBER SEPARATOR
GASOLINE RETURN
INLET VAPOR
PUMP
Patented

FIGURE IV-8 ADSORPTION-ABSORPTION FLOW SCHEMATIC - MCGILL

Source: McGill Americas, Inc.

- the rich liquid containing the absorbed vapours in the separator is returned to storage;
- the small quantity of vapours from the top of the absorber is returned to the adsorbing carbon bed;
- heat exchangers are provided to remove built up heat due to adsorption.

Both companies have many units in place in the United States operating for up to 10 or 11 years. They are reliable processes requiring only quarterly or semi-annual preventative maintenance and regular changes of glycol for the vacuum pump seal. Daily half-hour checks of the equipment are also recommended to ensure that everything is operating as it should. Motor operated valves which control the switching of flow between carbon beds are the most frequently replaced part according to Garteiser (1988).

Maintenance costs reported by Garteiser (1988) and Halbleib (1988) are typically less than $ 10,000 (CDN) per year which is in the range of 1 - 5% of the purchased capital cost of the units. Energy requirements account for most of the operating costs. Typical energy requirements are shown in Figure IV-9. Actual requirements will depend on the connected horsepower.

Regular emissions tests such as the one shown in Table IV-4 show that the adsorption-absorption process easily meets the US EPA requirements of 35 mg of hydrocarbon released per litre of gasoline transferred (35 mg/L). Garteiser (1988) confirmed these claims.

Adsorption in general is enhanced by higher hydrocarbon concentrations, lower operating temperatures and higher operating pressures. Regeneration is achieved under the reverse conditions. Increasing the temperature or decreasing the pressure will desorb the hydrocarbons from the carbon beds. Purging with a gas such as air which is only weakly attracted to carbon provides a third method of regenerating the carbon beds. The McGill and Zink units use pressure swing and purge air to accomplish regeneration.

Adsorption efficiency also tends to be higher for heavier molecular weight components so it is reasonable to assume that the aromatics would be removed to a greater degree than the butanes and pentanes which form the bulk of the vapour mixture.

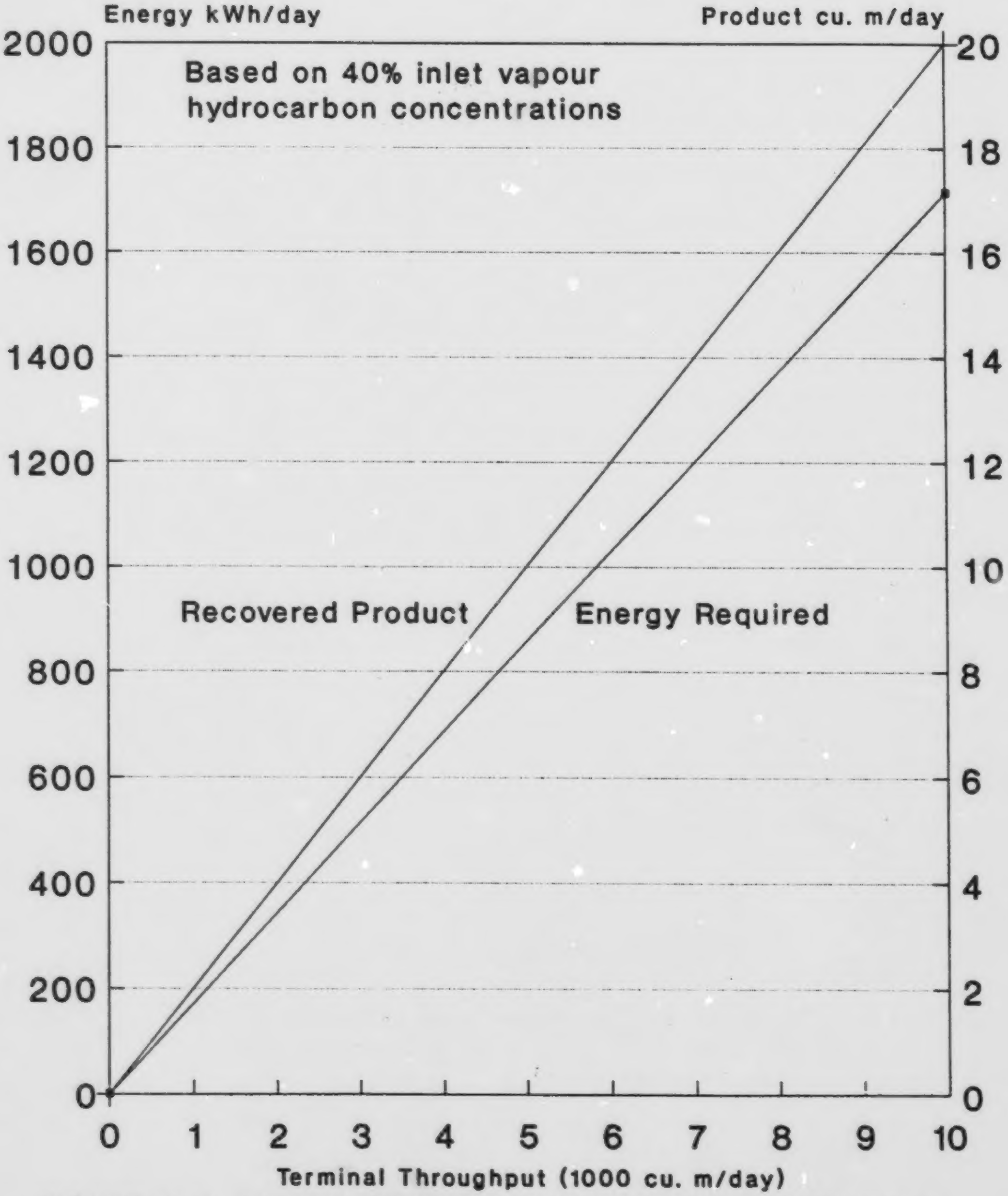


FIGURE IV-9 TYPICAL RECOVERY AND ENERGY REQUIREMENTS FOR ADSORPTION-ABSORPTION SYSTEMS

Source: John Zink Company

TABLE IV-4 TYPICAL VOC EMISSIONS FROM THE ADSORPTION-ABSORPTION PROCESS; EXXON OIL TERMINAL, BENICIA, CALIFORNIA

TIME	EMISSION RATE mg/L
1200 - 1300	8.4
1300 - 1400	13.2
1400 - 1500	6.0
1500 - 1600	12.0
1600 - 1700	12.0
1700 - 1800	6.0
1800 - 1900	8.4
1900 - 2000	9.6
2000 - 2100	3.6
2100 - 2200	9.6
2200 - 2300	6.0
2300 - 2400	7.2
2400 - 0100	15.6
0100 - 0200	4.8
0200 - 0300	8.4
0300 - 0400	9.6
0400 - 0500	8.4
0500 - 0600	12.0
0600 - 0700	6.0
0700 - 0800	8.4
0800 - 0900	16.8
0900 - 1000	7.2
1000 - 1100	10.8
1100 - 1200	3.6
1200 - 1200 (24 hours)	8.4

Source: "Performance Evaluation Test Report No. C-85-015" - State of California Air Resources Board

An advantage of the adsorption/absorption process is the potential to shut-down during periods of idle operation. The Zink process in particular will shut down the vacuum pump if the control unit senses that the carbon beds have sufficient capacity remaining. The vacuum pump will start-up as soon as the need for regeneration is detected. This demand type of operation could save energy especially when there is a considerably long down-time or lull in the loading operation.

John Zink Company has at least one unit operating in the Seattle area according to Halbleib (1988). The Point Wells Terminal reports satisfactory operation of the vapour recovery process.

5. Refrigeration

Schematics of two refrigeration processes which have been in use in the U.S. market to control the emissions of VOC's from the bulk transfer of gasoline are shown in Figures IV-10 and IV-11. These units are supplied by Edwards Engineering, Corp. and Tenney Engineering, Inc., respectively. These units are available in a variety of sizes which would meet the requirements within the study area.

Both systems are based on cascade refrigerating processes which cool refrigerant down to -70 to -80°C or colder in two stages. Both systems recover a liquid product which can easily be measured. The two systems differ primarily by the addition of a precooler in the Edwards system. This precooler helps to prevent excessive hydrate build up by removing as much of the water vapour as possible before the vapour enters the low temperature condenser. Another difference is the use of a cold brine reservoir by Tenney which acts as a buffer or reserve of cooling capacity.

Briefly, the operation of the systems are as follows:

(a) Edwards Engineering

Vapours collected during tank truck loading pass through an underground knock-out tank before entering the finned tube precooler at 1°C where as much of the water vapour is removed as possible without forming hydrates. The condensate is sent to a decanter to separate the water and condensed hydrocarbons. Utilizing a precooler helps to reduce energy costs, reduces water hydrate problems and standardizes the condition of vapours entering the low temperature condensers.

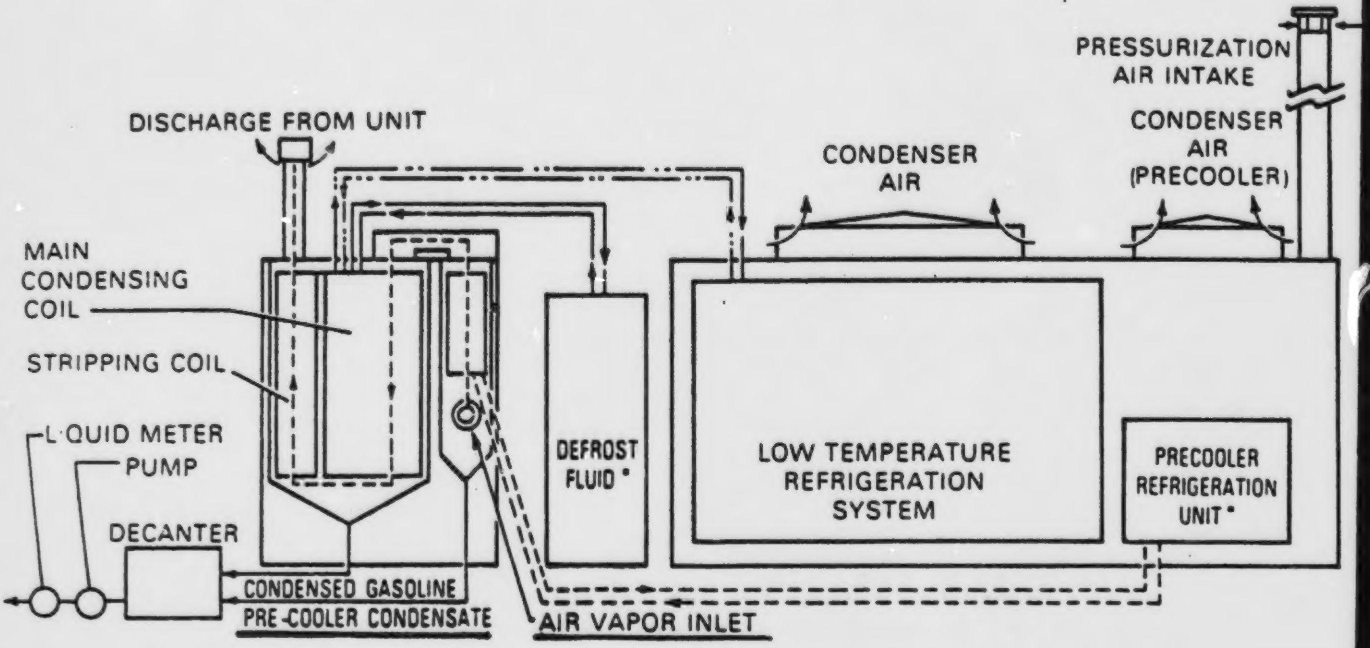

PRESSURIZATION AIR INTAKE
DISCHARGE FROM UNIT
CONDENSER AIR
CONDENSER AIR (PRECOOLER)
MAIN CONDENSING COIL
STRIPPING COIL
LIQUID METER
PUMP
DECANTER
DEFROST FLUID *
LOW TEMPERATURE REFRIGERATION SYSTEM
PRECOOLER REFRIGERATION UNIT *
CONDENSED GASOLINE
PRE-COOLER CONDENSATE
AIR VAPOR INLET

FIGURE IV-10 REFRIGERATION SCHEMATIC - EDWARDS

Source: Edwards Engineering, Corp.

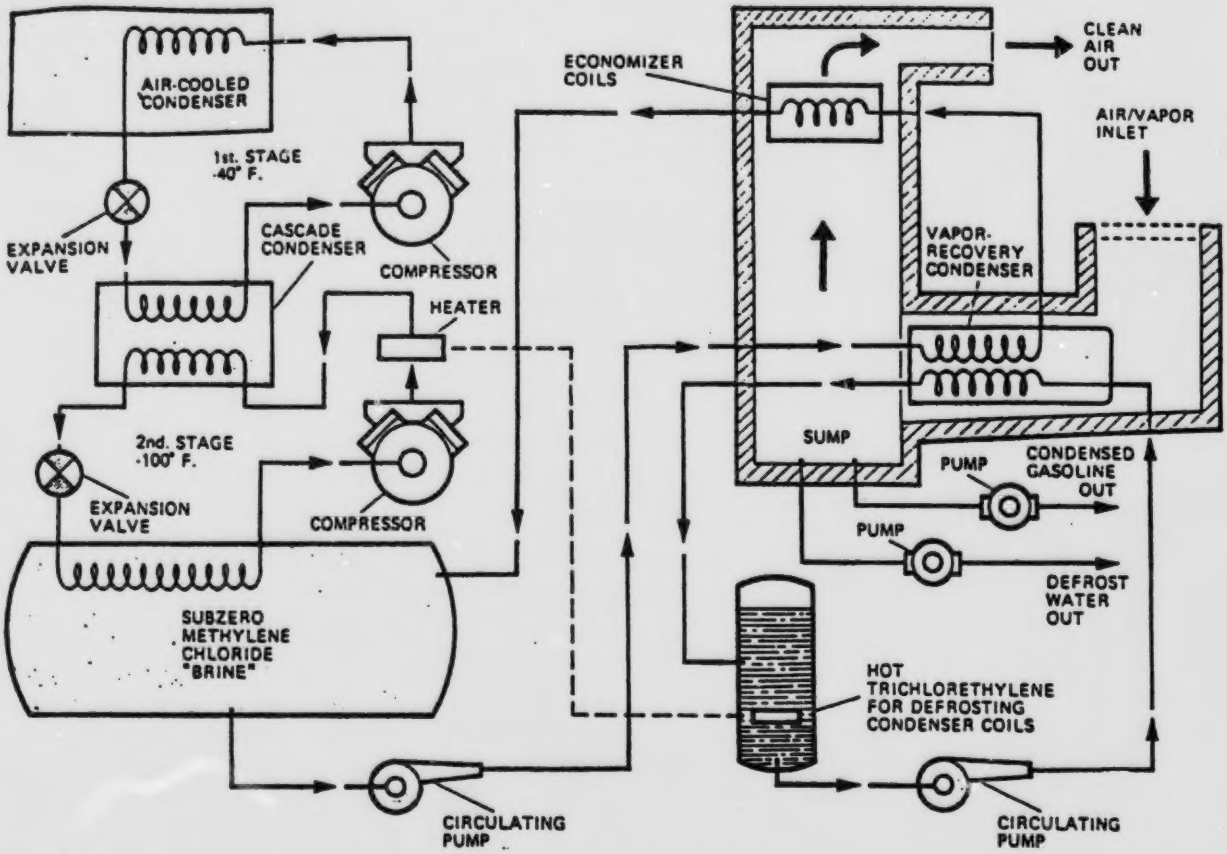

AIR-COOLED CONDENSER
1st. STAGE -40° F.
EXPANSION VALVE
CASCADE CONDENSER
COMPRESSOR
HEATER
2nd. STAGE -100° F.
EXPANSION VALVE
COMPRESSOR
SUBZERO METHYLENE CHLORIDE "BRINE"
CIRCULATING PUMP
ECONOMIZER COILS
CLEAN AIR OUT
AIR/VAPOR INLET
VAPOR-RECOVERY CONDENSER
SUMP
PUMP
CONDENSED GASOLINE OUT
PUMP
DEFROST WATER OUT
HOT TRICHLORETHYLENE FOR DEFROSTING CONDENSER COILS
CIRCULATING PUMP

FIGURE IV-11 REFRIGERATION SCHEMATIC - TENNEY

Source: Tenney Engineering, Inc.

The precooled vapours next enter the low temperature condenser at -80°C or colder where a hydrate containing 50 - 80% hydrocarbon is formed on the coils. The coils are designed to handle a considerable hydrate build-up without significantly affecting the heat transfer rate or pressure drop. Periodic defrosting for 1 hour every 24 hours is necessary to remove hydrate formation. The coils can be constructed in two halves to allow for alternate defrosting allowing for continuous service; although at half capacity during defrosting.

Hydrocarbon condensate from the low temperature coils is collected in a drain pan located under the coils. From there, the condensate passes into a decanter where hydrocarbon condensate passes over a weir to a product collection chamber. Float switches control the pumping to storage tanks. The water is drained separately to a waste sump.

(b) Tenney Engineering, Inc.

The Tenney system cools the vapour-laden air in one stage unlike the Edwards system. Another difference is the use of a cold brine reservoir at -70°C to cool the hydrocarbon-air mixture. During peak truck loading periods the reservoir provides the additional cooling capacity which would otherwise have to be supplied by larger compressors.

Vapours collected during tank truck loading pass through an underground knock-out tank before entering the finned-tube gasoline recovery condenser. Condensed vapours flow down into a sump where it can be decanted and pumped to storage.

The Tenney system also requires daily defrosting for 1 hour.

Both companies have many units in place, however, Tenney has not installed a unit for these purposes for several years. Furthermore, increased operating and capital costs to achieve the same discharge limits as carbon adsorption-absorption systems have discouraged some oil companies from the refrigeration process according to Halbleib (1988) and Garteiser (1988).

Maintenance costs reported by industry exceed the $ 10,000 (CDN) per year estimated for the carbon adsorption-absorption units. It should be noted, however, that older refrigeration units were being compared to newer adsorption-absorption units. Energy requirements make up most of the operating costs. Figure IV-12 illustrates the typical recovery expected and energy required for an Edwards System. Actual requirements will depend on the connected horsepower.

Emission tests at Exxon in the United States showed that their units easily met the earlier regulations of 80 mg/L throughput but only one met the new regulations of 35 mg/L throughput. Note that these units were installed before the 35 mg/L limit was in effect. Based on design information supplied by Edwards, refrigeration systems can be designed to meet the 35 mg/L limit. This does require units sized up to three models larger than the model sized to meet the 80 mg/L limit. Depending on throughput, capital costs would increase by 15% or more to meet the more stringent limit.

The refrigeration capacity is improved by lower RVP and lower vapour temperature. Under normal conditions, these variables tend to offset each other. During the winter, RVP is higher and during the summer, RVP is lower. Therefore, refrigeration systems tend to operate at fairly constant capacity year round.

Low vapour pressure components tend to condense more readily than high vapour pressure components. Therefore, it is logical to expect that the aromatics will be removed to a greater extent than the butanes and pentanes which form the bulk of the vapour and have higher vapour pressures.

6. Thermal Oxidation

There are several major suppliers of this type of equipment to the United States market - National Air Oil Group, Hirt Combustion Engineers, McGill Americas, Inc. and John Zink Company. These incinerators are available in a variety of sizes suitable for the study area applications. By far the simplest of the three vapour control processes, the thermal oxidizers, typically include:

- specially designed anti-flashback burner(s);
- automatic ignition pilot with a continuous monitor;
- motor operated block valve(s);
- flame arrestor(s);

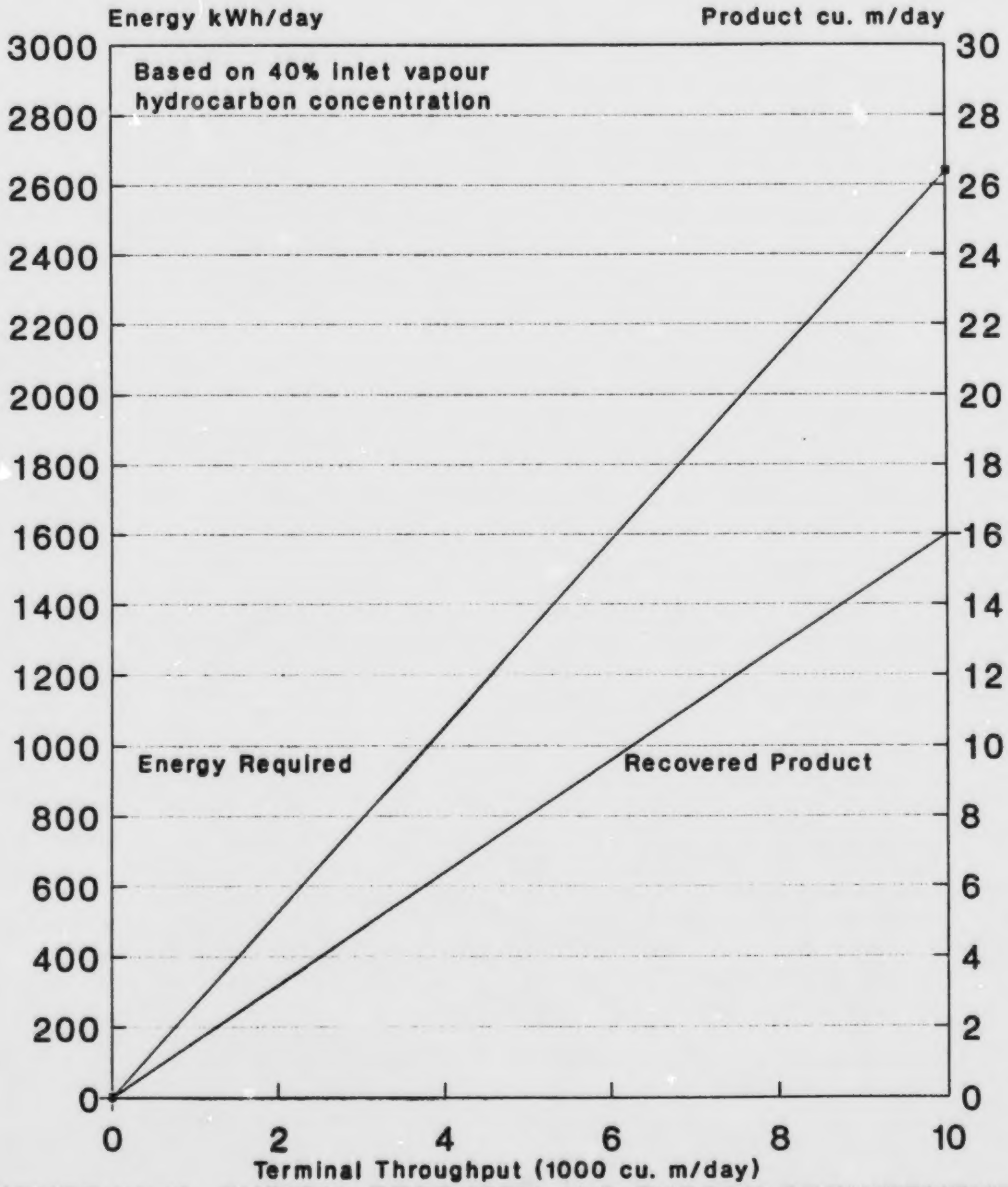


FIGURE IV-12 TYPICAL RECOVERY AND ENERGY REQUIREMENTS FOR REFRIGERATION SYSTEMS

Source: Edwards Engineering, Corp.

- liquid seal;
- instrumentation and master control panel;
- air-assist blower.

These units can be open-flame types where the flame is visible or they may be enclosed in a casing with ceramic fibre refractory lining where the flame is not visible. Heat recovery is a possible add-on feature that can be considered. A thermal oxidation system is shown in Figure IV-13.

The operation of a thermal oxidizer for vapour control begins with a brief air purge followed by pilot ignition. Once the pilot is on, truck loading may commence.

There are a variety of vapour combustion system set-ups available. Two typical installations are described below.

(a) John Zink Company

Once the pilot is ignited, vapours displaced during truck loading operations pass through a condensate tank where some liquid drop-out takes place. Vapours flow to a liquid seal drum where they bubble through a water or water/antifreeze mixture. A pressure monitoring controller detects the pressure and automatically opens a vapour block valve allowing vapour to flow through a flame arrestor to the burner. Combustible vapours are ignited by the pilot and burned. An air assist blower provides combustion air and mixing energy to the burner tip to assure smokeless combustion.

The same pressure monitoring controller will also automatically close the vapour block valve if vapour flow is insufficient to maintain minimum burner velocity. The pilot and air-assist blower remain on for a brief time after loading is complete.

(b) Hirt Combustion Engineers

Operation of the Hirt system differs from the Zink system primarily by the addition of a vapour holding tank between the condensate tank and the burner. A small compressor is also used after the vapour holder.

The vapour holding tank has an internal bladder which can expand or contract as vapour flow increases or decreases. An advantage of having a vapour holding tank in-line is that vapours tend to be saturated and well above

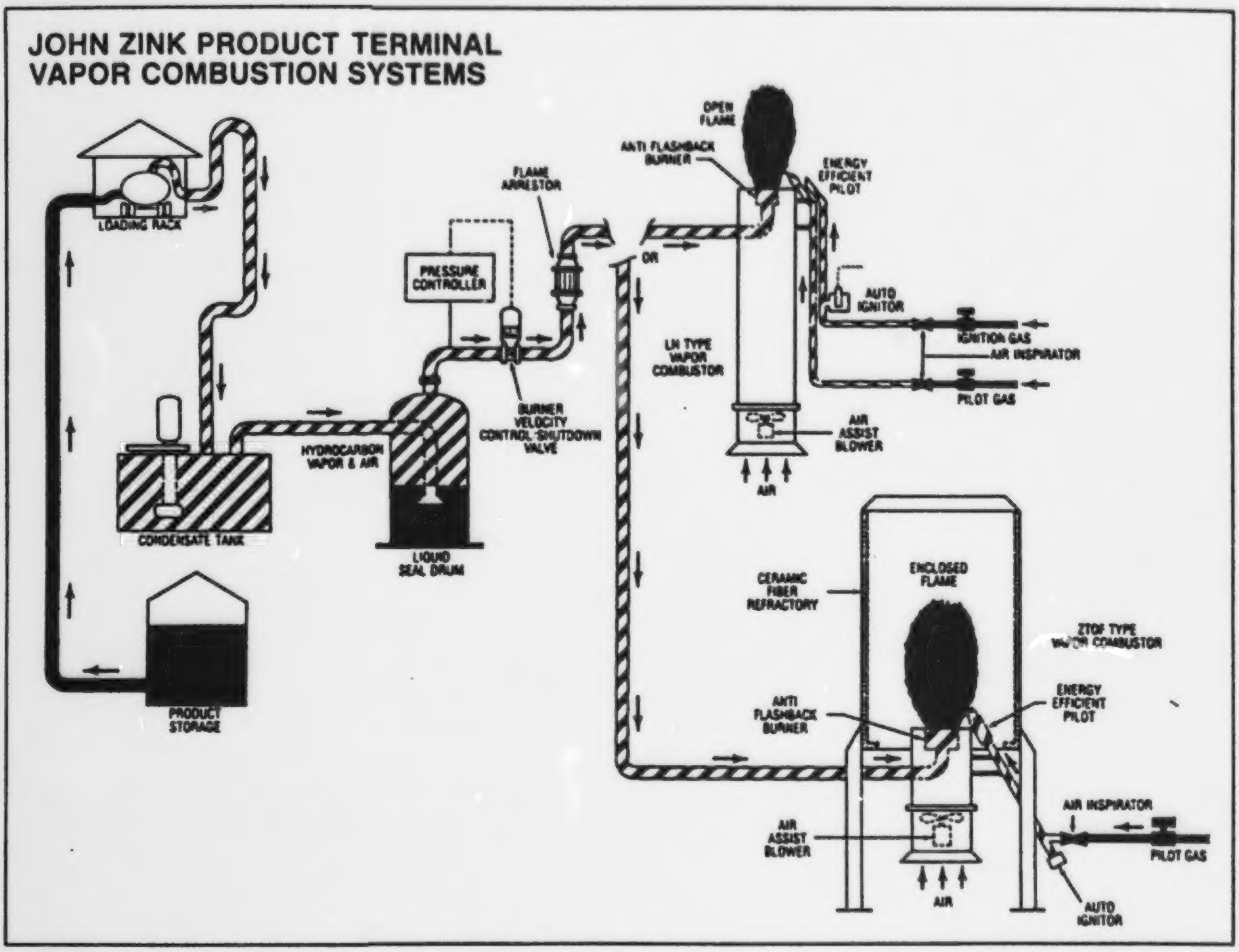

JOHN ZINK PRODUCT TERMINAL
VAPOR COMBUSTION SYSTEMS
LOADING RACK
CONDENSATE TANK
PRODUCT STORAGE
HYDROCARBON VAPOR & AIR
LIQUID SEAL DRUM
PRESSURE CONTROLLER
BURNER VELOCITY CONTROL SHUTDOWN VALVE
FLAME ARRESTOR
OR
OPEN FLAME
ANTI FLASHBACK BURNER
ENERGY EFFICIENT PILOT
AUTO IGNITOR
IGNITION GAS
AIR INSPIRATOR
PILOT GAS
LH TYPE VAPOR COMBUSTOR
AIR ASSIST BLOWER
AIR
CERAMIC FIBER REFRACTORY
ENCLOSED FLAME
ZTOF TYPE VAPOR COMBUSTOR
ANTI FLASHBACK BURNER
ENERGY EFFICIENT PILOT
AIR INSPIRATOR
PILOT GAS
AIR ASSIST BLOWER
AIR
AUTO IGNITOR

FIGURE IV-13 FLOW SCHEMATIC OF A THERMAL OXIDATION SYSTEM

Source: John Zink Company

the upper explosive limit. During cold periods a modest amount of condensate may also be collected. The saturated vapour stream also requires less pilot fuel to maintain proper combustion temperatures.

Thermal oxidation systems are easily the lowest capital cost means of controlling VOC emissions from bulk loading operations. Their lack of product recovery is a key factor to be considered in the selection of a vapour control process. Garteiser (1988) and Halbleib (1988) tend to favour vapour recovery processes rather than vapour destruction processes as their primary means of controlling VOC emissions. In some cases in the USA where state authorities do not allow even brief violations of the 35 mg/L emission limit, thermal oxidizers have been installed as an affordable back-up system according to Garteiser (1988).

Maintenance costs reported by Hirt Combustion Engineers average under 5%/yr of capital costs. Oil industry contacts could not provide reliable verification of this estimate. The major operating expense for thermal oxidizers would be for fuel to run the pilot. Hirt estimated the fuel requirements for burners suited to handle the sizes of tank truck loading terminals in the Lower Mainland at 0.2 to 0.4 GJ/h with natural gas as the pilot fuel.

Reduction of VOC emissions is reported to be in excess of 99% by NAO, Inc. The actual reduction percentage is somehwat dependent on the inlet hydrocarbon concentration. Therefore, an alternative method of evaluating the performance of a thermal oxidizer is to look at the discharge concentration. NAO, Inc. claim limits of 7 mg/L or better. The US EPA (August 18, 1983 Federal Register) accepts thermal oxidizers as being able to meet or exceed the 35 mg/L emission standard.

In one test of NAO equipment, benzene vapours were controlled to a level of 1 ppm by volume at an optimum chamber temperature of 980°C which is higher than the unit's normal operating temperature. Typical burners operate at 700 - 800°C. No CO was detected and NO_x levels were between 15 and 20 ppm. No initial benzene concentration was provided.

It seems reasonable to assume that the aromatic components are burned as effectively as the bulk vapour.

C. Service Stations

There are two major sources of vapour emissions at service stations. Vapour balancing can be applied between the delivery truck's tank and the underground tanks at the station during deliveries of gasoline. Vapour balancing can also be applied between the vehicle gasoline tank and the underground tanks at the station during vehicle refueling. Vehicle refueling vapour balancing would not be installed alone. Instead it would be installed simultaneously or subsequently to the delivery vapour balancing. Therefore, the names Stage I and Stage II have been applied in the United States to the delivery and vehicle refueling vapour balancing systems respectively.

1. Delivery Vapour Balancing

Vapour balancing during deliveries requires a vent line from the underground storage tanks to return vapours to the delivery truck as shown in Figure IV-14. A simple way is to modify the existing gasoline drop line with a "WYE" type fitting which splits the flow between delivered gasoline and returned vapours. Alternatively, coaxial fittings and piping could be used for this purpose. Both of these alternatives involves some excavation around the existing gasoline drop lines and subsequent backfilling and re-paving.

In California, the Air Resources Board Report to the Legislature (1982) reported a requirement to demonstrate in-use efficiency of 95% before delivery vapour balancing would be certified. This limit was recommended because it could clearly be achieved based on certification test results. Vapour balancing was implemented in the early 60's in California.

2. Vehicle Refueling Vapour Balancing

Figure IV-14 illustrates a service station fitted for vehicle refueling vapour balancing. Also illustrated in that figure is a manifold system to connect the dispensers with a storage tank. The tanks in turn are connected by their vapour vent lines. The vapour processor shown is an optional piece of equipment to control emissions as a result of tank breathing.

In addition to the manifold and piping system to connect the tanks to the dispensers, special nozzles, hoses, swivels and other fittings are required at the dispensers to allow for vapour balancing during vehicle refueling. The nozzles are equipped with a bellows and clip to allow for a tight seal with the vehicle gasoline tank.

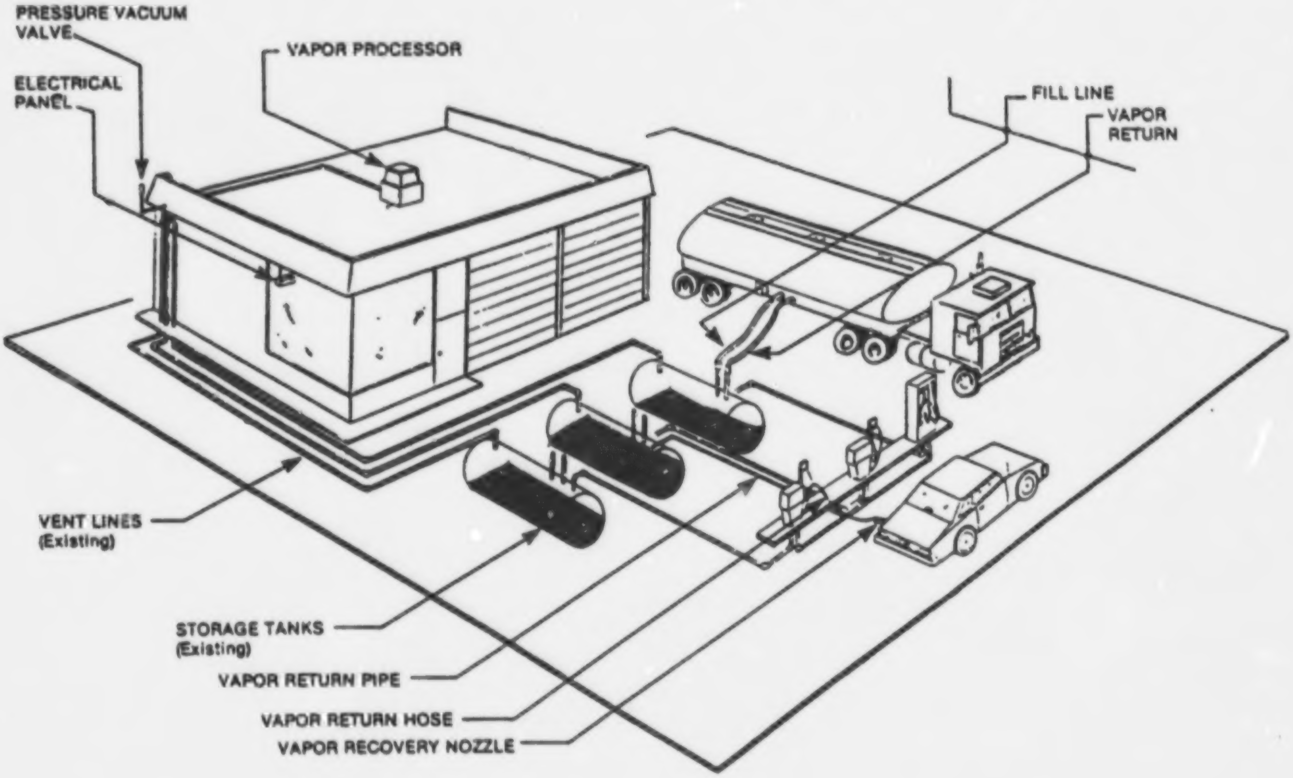

PRESSURE VACUUM VALVE
VAPOR PROCESSOR
ELECTRICAL PANEL
FILL LINE
VAPOR RETURN
VENT LINES (Existing)
STORAGE TANKS (Existing)
VAPOR RETURN PIPE
VAPOR RETURN HOSE
VAPOR RECOVERY NOZZLE

FIGURE IV-14 HIRT COMBUSTION ENGINEERS VCS-200 VAPOR NET SYSTEM

According to McPherson (1988), early designs of dispensing nozzles and hoses were heavy and awkward to use prompting the use of assist systems at service stations. These assist systems provided some form of suction at the vehicle gasoline tank-nozzle interface so that tight seals would not be required. The assist systems were lighter and easier to handle than the balance systems.

Recently, improved designs have reduced the weight and handling problems associated with balance systems. Therefore, balance systems are the present choice for most service stations according to McPherson (1988).

Relative in-use effectiveness is a contentious issue in the U.S. at present. This arises from the split in support for and against vehicle refueling vapour balancing. Proponents for vapour balancing such as Multinational Business Services, Inc. (1988) feel that a lower bound of 62% and an upper bound of 92+% for vapour capture are achievable based on the latest data from California and Washington, D.C. The U.S. EPA has tended to favour the use of on-board carbon cannisters over vapour balancing because of higher in-use effectiveness; 83 - 89% for on-board controls compared to 48 - 66% for vapour balancing. Regular inspections and enforcement programs may be the key to improving the in-use effectiveness of vapour balancing. The extent of enforcement of control regulations ultimately determines the in-use effectiveness attainable. Case in point is Washington, D.C. where monthly inspections and issuances of violation tickets have helped to decrease the percentage of faulty nozzles in operation. Washington, D.C. previously had a very high percentage of faulty nozzles due to less frequent inspections and the need to prosecute through the courts.

D. Control of VOC Emissions by RVP Reduction

The following discussion presents an overview of the use of RVP reduction as a control strategy to reduce VOC emissions from fuel marketing. A separate project is being completed by others for the Petroleum Association for Conservation of the Environment (PACE) which examines RVP reduction options in detail.

1. Background to Gasoline Blending

Gasoline is a heterogenous mixture blended from intermediate products of the refining process. Common components included in gasoline are listed in Table IV-5 (Gary and Hardweek (1975)). Note that the lead levels are not representative of levels in Canadian fuel. The two most important characteristics of gasoline are the vapour pressure and the octane number (Leffler (1985)).

TABLE IV-5 REGULAR BLENDING COMPONENT VALUES

NO.	COMPONENT	RVP	MON	MON^1 1.59 g*	MON^1 3.17 g*	RON	RON^2 1.59 g*	RON^2 3.17 g*	GRAVITY °API
1	i-C_4	71.0	92.0	99.3	102.0	93.0	100.4	103.2	120.0
2	n-C_4	52.0	92.0	98.8	101.5	93.0	99.9	102.5	111.0
3	i-C_5	19.4	90.8	105.7	107.5	93.2	101.3	103.4	95.0
4	n-C_5	14.7	72.4	87.2	92.3	71.5	86.2	90.7	88.9
5	i-C_6	6.4	78.4	90.6	95.1	79.2	91.3	94.6	76.5
6	Hydrocrackate, C_5-C_6	15.5	85.5	96.7	100.8	89.2	96.8	99.3	86.4
7	Hydrocrackate, C_6-190°	3.9	73.7	86.3	91.4	75.5	88.4	93.4	
8	Hydrocrackate, 190-250°C	1.7	75.6	84.6	87.9	79.0	88.3	92.2	55.5
9	Lt thermal gaso.	9.9	73.2	77.3	78.8	80.3	87.3	90.7	74.0
10	C_6^+ lt thermal gaso.	1.1	68.1	71.5	72.7	76.8	82.4	86.3	
11	Coker gaso.	3.6				67.2		82.5	57.2
12	C_5^+ TCC gaso.	4.0	76.6	80.6	82.1	85.5	90.7	93.0	
13	C_6^+ TCC gaso.	2.6	75.8	80.0	81.0	84.3	89.9	92.3	
14	FCC gaso., 200-300°C	1.4	77.1	81.4	83.0	92.1	95.3	96.3	49.5
15	FCC C_5^+ gaso.	4.4	76.8	78.8	79.4	92.3	94.8	95.8	57.2
16	Hydrog C_5-200° FCC gaso.	14.1	81.7	88.9	91.7	91.2	98.4	100.3	
17	Hydrog C_5^+ FCC gaso.	13.1	80.7	90.0	91.7	91.0	97.7	100.0	
18	Hydrog 300-400°C FCC gaso.	0.5	81.3	84.2	85.7	90.2	95.5	97.5	
19	Reformate, 94 RON	2.8	84.4	89.3	91.2	94.0	99.4	100.8	45.8
20	Reformate, 98 RON	3.2	86.5	91.1	92.5	98.0	101.0	102.2	43.1
21	Reformate, 100 RON	4.2	88.2	92.3	93.7	100.0	103.1	104.0	41.2
22	Aromatic concentrate	1.1	94.0	94.6	95.4	107.0	109.4	111.4	
23	Alkylate, $\overline{C}_4$	4.6	95.9	101.9	103.4	97.3	102.0	104.0	70.3
24	Alkylate, $\overline{C}_5$	11.0	88.8	99.2	103.0	89.7	99.2	103.1	
25	Polymer	8.7	84.0	85.4	86.5	96.9	99.0	99.7	
26	Absorber gaso.	21.3	83.2	95.4	99.4	83.9	96.1	98.2	
27	LSR gaso. (C_5-180°C)	11.1	61.6	73.7	80.6	66.4	77.3	83.5	78.6
28	LSR gaso. isomerized, once-through	13.5	81.1	98.1	100.6	83.0	92.3	98.0	80.4
29	Hvy SR gaso.	1.0	58.7	72.5	78.2	62.3	73.5	79.3	
30	Lt hydrocrackate	12.9	82.4	93.7	97.9	82.8	94.8	98.4	79.0

TABLE IV-5 REGULAR BLENDING COMPONENT VALUES (CONTINUED)

NO.	COMPONENT	RVP	MON	MON[1] 1.59 g*	MON[1] 3.17 g*	RON	RON[2] 1.59 g*	RON[2] 3.17 g*	GRAVITY °API
31	Hvy hydrocrackate	1.1	67.3	79.2	83.5	67.6	80.8	85.6	
32	Hydrog lt cat gaso., C_5^+	23.9	80.9	92.6	95.7	83.2	94.5	97.4	
33	Hydrog lt cat gaso., C_6^+	5.0	74.0	81.4	84.0	86.3	92.2	94.4	

* Grams lead per gallon

[1] MON - Motor Octane Number
[2] RON - Research Octane Number

Source: Gary, J.H. and Hardweek, G.E. (1975)

Vapour pressure is a measure of volatility. Reid Vapour Pressure (RVP), the vapour pressure measured following procedures defined in ASTM (D323) is used in the refining industry to measure the volatility of gasoline. The RVP must be high enough to ensure partial volatilization of gasoline at low ambient temperatures and low enough to prevent excessive volatilization at high temperatures. RVP has been found to be a good measure of a gasoline's ability to meet these conditions.

RVP typically ranges from 55 kPa (8 psi) in southern United States during the summer and 90 kPa (13 psi) or more in Canada during the winter. Most components of gasoline have RVP's lower than this range. Therefore, butane is used to adjust the RVP of the final gasoline product to the desired range. Since butane is less costly than the other components, maximizing the butane content has economic incentives.

Butanes for blending are either made in refineries or are purchased from natural gas plants. Normal butanes are used more for RVP adjustment than iso-butane for two reasons. First, its RVP is lower, allowing for more butane to be blended. Second, iso-butane is often used in alkylation units and is, therefore, in shorter supply.

Another attractive aspect of blending butane into gasoline is its relatively high octane number. The octane number measures the tendency of a gasoline to knock in an engine. Knocking is caused when a gasoline is compressed to the point of self-ignition prior to the piston reaching the top of its stroke. Since knocking reduces power and is hard on the mechanical parts, it must be avoided. Engines which produce more power per unit displacement often use higher compression ratios, requiring higher octane gasolines.

Lead in the form of tetraethyl or tetramethyl lead has been used to increase the octane rating of gasoline without affecting its RVP. Since Environment Canada has announced an intention to phase out lead in gasoline by December 1, 1990, the refining industry will have to adjust its blending components to retain the required octane rating. To make up lost octane, the industry can increase some of the higher octane aromatic components or add octane boosters.

2. Methods of RVP Reduction

Felton & McCarthy (1987) analyzed the consequences of reducing gasoline volatility under several marketing scenarios in the USA. They report that refiners have a number of options available to them which are classified under three categories:

(a) blending operations;

(b) existing processes;

(c) new/modified processes.

Reducing butanes from the gasoline blend is the most direct means of reducing gasoline volatility. If butane content is reduced, other high octane sources must be substituted. Furthermore, the reductions in butane necessary to significantly lower volatility could cause butane value to fall to fuel value according to Felton and McCarthy (1987).

Reducing other high volatility components such as light, straight-run naphtha from the gasoline pool is an alternative means available to refiners. Again, reductions of significant volumes of these components could drop their alternative values.

Some gasolines use oxygenates (alcohols and ethers) as octane enhancers. Alcohols are also highly volatile. Consequently, displacing alcohols would reduce gasoline volatility. However, other high octane components would need to be substituted for the displaced alcohols.

Reducing catalytic reforming and fluid catalytic cracking (FCC) severity would lower the production of butanes, thereby reducing gasoline volatility. However, this would also lower the reformate and FCC gasoline octane rating and the FCC olefin production, a feedstock for condensation units, which would also reduce the gasoline octane rating.

One of the best options refiners have to reduce gasoline volatility with existing processes is to increase utilization of condensation processes such as alkylation, catalytic polymerization and dimerization. This option would reduce volatility and also increase pool octanes by converting butylenes into high-octane alkylate, catalytic polymerization gasoline and dimate. Furthermore, any additional methyl-tertiary-butyl ether (MTBE) capacity could be utilized to convert refinery isobutylene to a low RVP, high-octane MTBE.

Modifications to existing refinery capacity or additions of new process capacity can also be made to yield lower volatility blend components. Examples of modifications are:

(a) improvements to reformer catalyst;

(b) modifications to lower reformer operating pressure;

(c) addition of a fourth swing reactor, or conversion to a continuous reforming process which would reduce production of butanes and Liquid Petroleum Gases thereby improving gasoline yield and octane.

(d) new alkylation, catalytic polymerization and dimerization capacity would allow complete conversion of light olefins to low vapour pressure, high-octane gasoline;

(e) MTBE capacity could be added, but would have to compete for available isobutylene feedstock with condensation processes and petrochemical markets;

(f) low vapour pressure, high octane ether could be produced by converting FCC and coker C_5+ olefins in the new British Petroleum Etherol process;

(g) processes to produce low-volatility, high-octane gasoline could be added. These processes may be limited by economics;

(h) the UOP/BP Cyclar process which converts propane and butane into benzene could be added. This option is limited given that the benzene content of gasoline or benzene emissions from gasoline could be regulated.

Table IV-6 shows the relative impact of the new process options on octane and volatility (Felton and McCarthy (1987)).

The authors reviewed three supply/demand/pricing scenarios to estimate the impact of reduced gasoline volatility on the United States Refining Industry. The results of their linear programming which predicts the process additions under three market scenarios were as follows:

(a) shift to better reforming catalyst (R-62 type);

(b) addition to isomerization capacity;

(c) addition to MTBE capacity;

(d) the Etherol process was attractive under the higher price scenario.

A detailed survey of the entire U.S. refining industry by API was reported by Cunningham et al (1987). They reported on facility additions deemed economic for a 21 kPa (3 psi) RVP reduction from a 77 kPa (11.2 psi) base. These additions are presented in Figure IV-15.

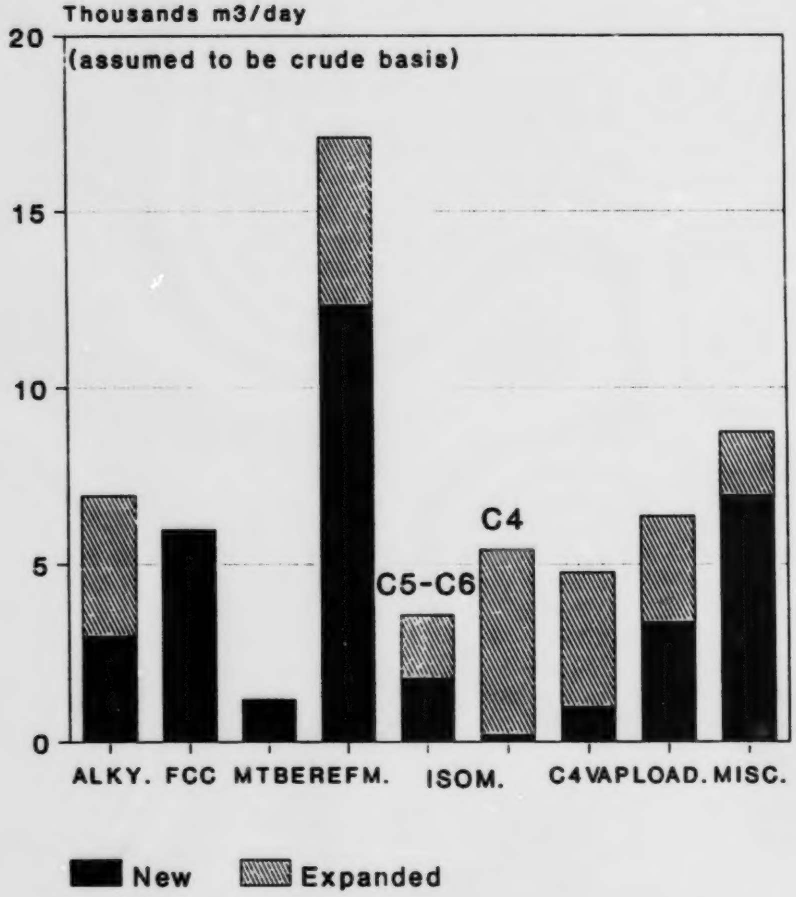
TABLE IV-6 STATUS AND IMPACTS OF PROCESS OPTIONS

NEW PROCESS OPTIONS	STATUS	OCTANE	VOLATILITY
Low Pressure Reforming (Conversion)	C	+	+
New Reforming Catalyst (R-62)	C	+	+
Add Fourth Reformer Reactor	C	+	+
New Continuous Reforming	C	+	+
FCC Octane Promoting Catalyst	C	+	-
FCC Heart Cut/Reforming	C	+	-
Alkylation	C	+	+
Catalytic Polymerization	C	+	+
Dimersol	C	+	+
BTX Extraction and Sale of Raffinates	C	+	+
Once Through Isomerization	C	+	-
Conversion to Recycle Isomerization	C	+	-
Recycle Isomerization	C	+	-
MTBE	C	+	+
Etherol	NC	+	+
Cyclar	D	+	+

Key Status: C Commercial; NC New Commercial; D Developing

Impact: + positive impact; - negative impact; 0 little effect

Source: Felton, J.R. and McCarthy, K.M. (1987)



ALKY	alkylation
FCC	fluidized catalytic cracking
MTBE	methyl-tertiary-butyl-ether
REFM	reforming
ISQM	isomerization
C4VAP	butane vapourizer
LOAD	loading rack capacity

FIGURE IV-15 FACILITY ADDITIONS DEEMED ECONOMIC EPA 1992 RVP - ENTIRE U.S.

Source: Cunningham et al (1987)

3. Impact of RVP Reductions on Industry and Emission

Fasullo (1988) focused on the effect of RVP reductions on the gas processing industry. He estimated that about one-third of the butane blended into gasoline in the United States was supplied by natural gas processors. A slight RVP reduction of 7 - 10 kPa (1 - 1.5 psia) would bring refiners into a position of butane self-sufficiency. Further reductions in RVP could displace more butane than is obtained from gas processing (Figure IV-16), turning the refiners into net sellers rather than purchasers of butane.

Fasullo suggests that few alternative markets exist for butane. Some possibilities he suggested included:

(a) use butane as a motor vehicle fuel;

(b) upgrade normal butane to high-value gasoline blend stocks or petrochemicals.

On the basis of information from the literature and from on-going test programs, Steber et al (1985) felt that RVP reduction was a cost-effective means of reducing hydrocarbon (HC) emissions. They rated RVP reduction to be competitive with vehicle refueling control strategies on the basis of cost effectiveness. Furthermore, RVP reduction could be implemented over a shorter time frame than vehicle refueling vapour balancing and onboard controls. RVP reduction to 62 kPa (9 psi) from 62 - 79 kPa (9 - 11.5 psi) in the summer was predicted to provide slightly greater HC control than by refueling control strategies.

Refueling, hot soak and diurnal losses are affected by RVP to different degrees. Refueling losses are affected by RVP and temperature. Diurnal losses are strongly affected by RVP, while hot soak losses are affected to a lesser degree as seen in Figure IV-17.

A reduction in summertime RVP to 62 kPa (9 psi) from current levels was expected to reduce vehicle HC emissions from 9 to 25%.

A test program reported on by Barth (1984) looked at the effect of RVP on evaporative HC emissions. The variables studied included the vehicle evaporative standard, the test fuel, and the test driving and preparation cycles.

The test conclusions were that an increase in fuel RVP significantly increased evaporative emissions. Most of the increase was due to diurnal emissions. Hot soak emissions were

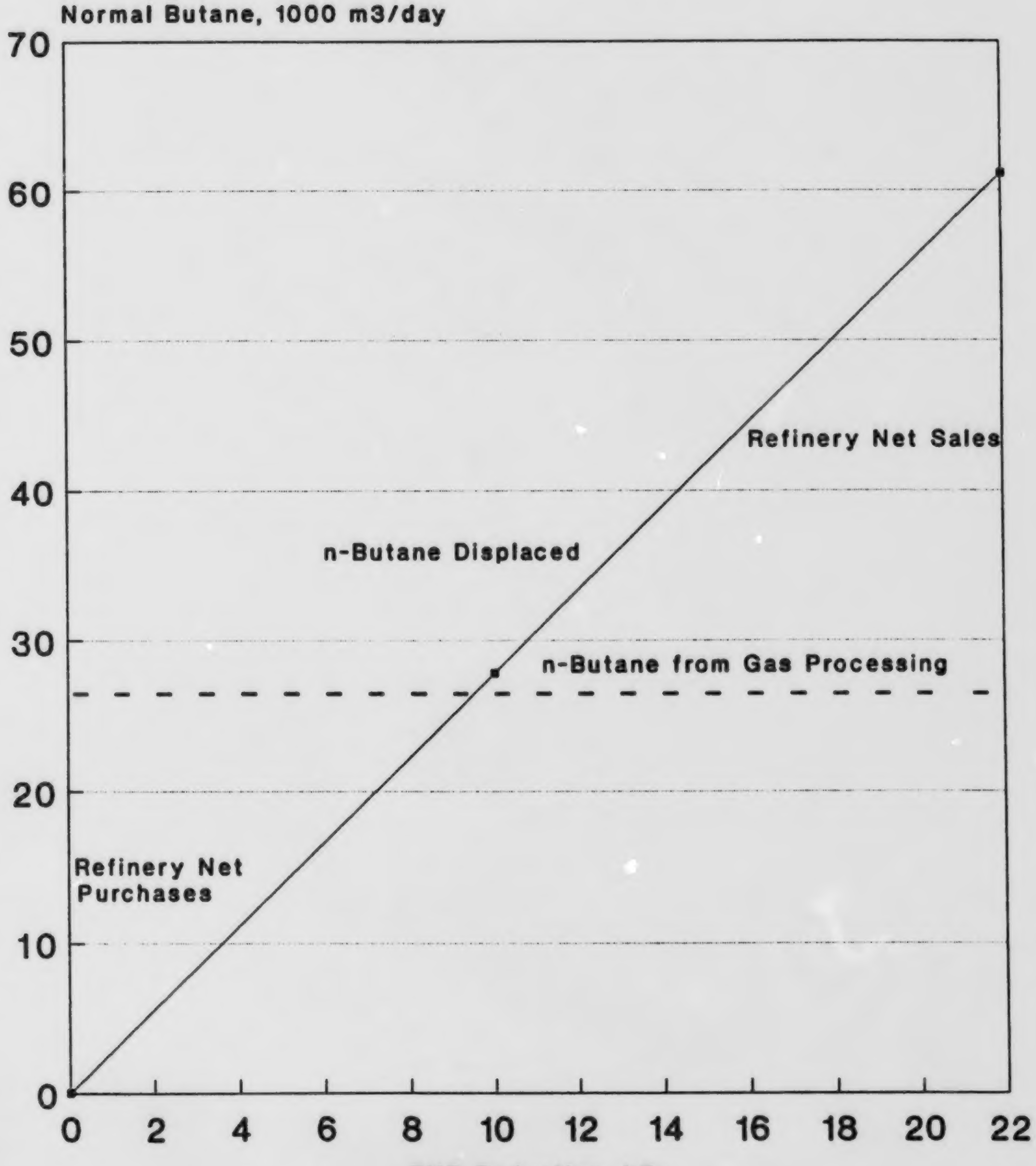


FIGURE IV-16 NORMAL BUTANE DISPLACEMENT DUE TO RVP REDUCTION

Source: Fasullo (1988)

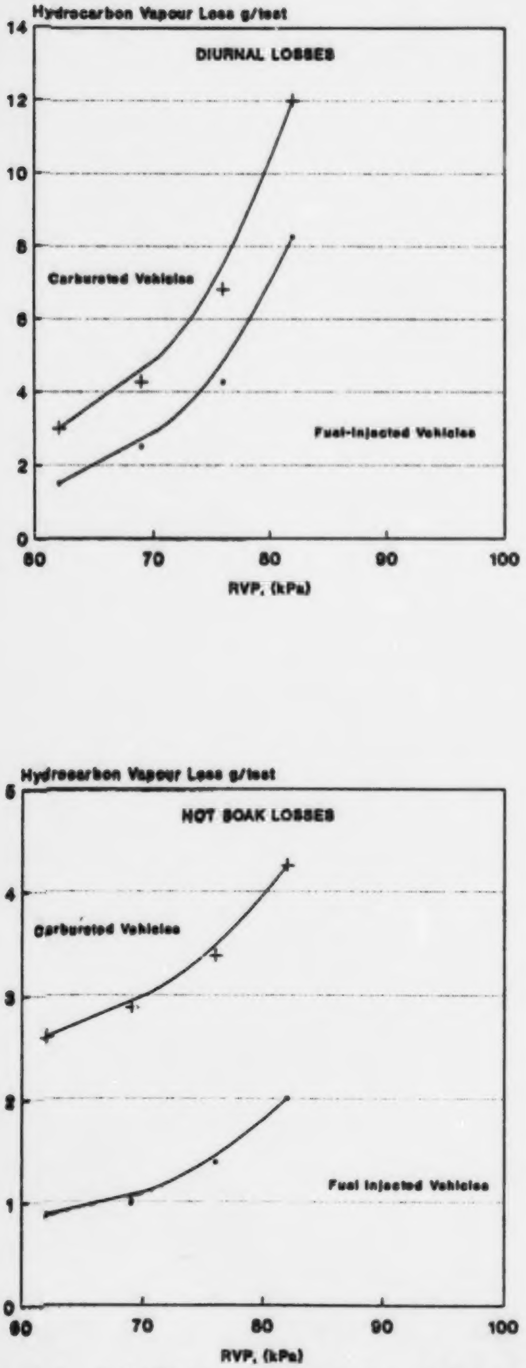


FIGURE IV-17 DIURNAL AND HOT SOAK LOSSES

Source: Stebar et al (1985)

30% higher using commercial fuel (RVP of 80 kPa or 11.7 psi) than with Indolene (RVP of 62 kPa or 9 psi) for vehicles meeting the 2.0 g standard (1982 model or later in the United States). For earlier model vehicles making the 6.0 g standard, the hot soak levels using commercial fuel were three times the levels with Indolene fuel. His findings are shown in Figure IV-18.

Exhaust emissions (HC, CO and NO_x) were not noticeably effected by the changes in RVP.

Exxon Research and Engineering Company (1979) using six different RVP fuels ranging between 41 and 83 kPa (6 and 12 psi) reported on evaporative and exhaust emissions. The test vehicles used were not representative of the U.S. motor vehicle fleet. Instead, vehicles each equipped with Evaporative Control Systems (ECS) in the 1974 - 1977 model years were selected. In general, the researchers found that the variation in emissions was dependent more on the ECS type of evaporative control system rather than on RVP.

Diurnal losses were low and relatively constant below 65 kPa (9.4 psi). At 81 kPa (11.8 psi) however, diurnal losses were several times higher. Hot soak losses tended to increase with increasing RVP.

Exhaust losses on the other hand, tended to be at a minimum for the 62 kPa (9 psi) fuel.

In a California Air Resources Board (CARB) report by Loop et al (1986), RVP reduction during the summer to 62 kPa (9 psi) from the ASTM specification of 69 kPa (10 psi) for that region is estimated to reduce all gasoline evaporative emissions by 30%. This reduction in RVP is expected to lose some of its impact as late model cars replace older vehicles.

Nelson (1969) estimated that a 21 kPa (3 psi) RVP reduction could reduce evaporative losses by about 50%. This corresponded to a 12% reduction in evaporative and tail pipe motor vehicle HC emissions during the summer and fall for the Los Angeles basin.

In a report for the American Petroleum Institute API, Automotive Testing Laboratories (1986) found that evaporative emissions decreased in a non-linear fashion as RVP was dropped from 81 kPa to 61 kPa (11.7 psi to 8.9 psi). The vehicles were all late models meeting the 2.0 g test standard with 18 of the 30 tested being fuel injected. About three-quarters of the evaporative emissions reduction came when the RVP was changed from 81 to 71 kPa (11.7 to 10.8 psi). Reducing RVP from 71 to 61 kPa also resulted in a slight reduction in exhaust emissions for carburated vehicles only.

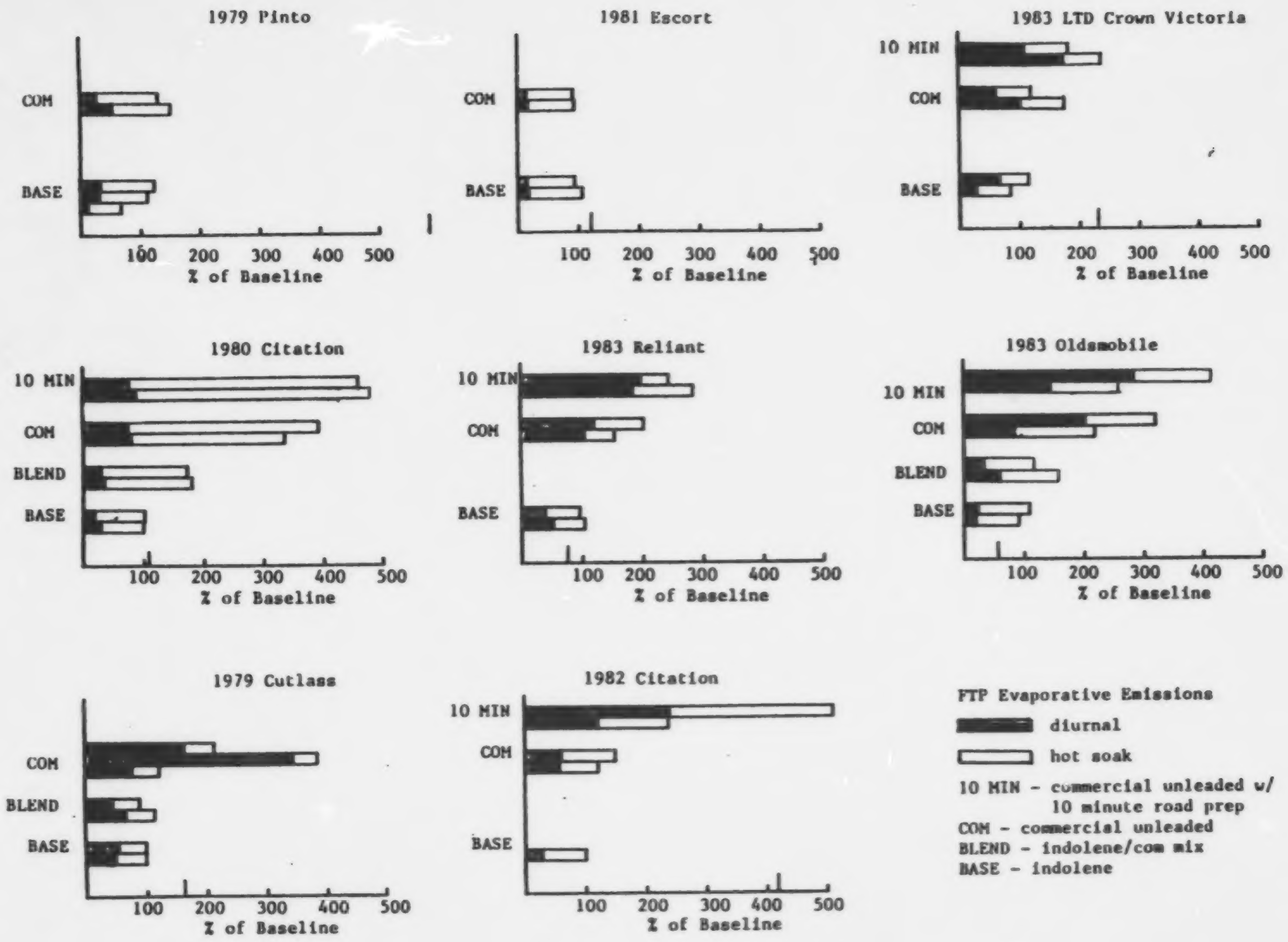


FIGURE IV-18 FEDERAL TEST PROCEDURE EVAPORATIVE EMISSION RESULTS

Diurnal losses were far more sensitive to changes in RVP. Hot soak losses increased only slightly with increasing RVP. Figure IV-19 illustrates these points.

One other finding shown in Figure IV-20 was that cars meeting the 2.0 g compliance standard were not effected by changes in RVP to the extent that cars failing the standard were affected. This also implies that as newer cars replace the older ones, RVP will have a steadily diminishing impact on evaporative emissions.

Intille (1985) remarked that RVP reductions below 62 kPa (9 psi) will continue to reduce evaporative emissions. He cautioned, however, that at the same time, exhaust emissions would begin to increase. Eventually at about 41 kPa (6 psi) the increased exhaust emissions would override any beneficial effects of reduced evaporative emissions.

Based on responses to questionnaires sent to representatives of the petroleum and auto industries, Venturini et al (1975) assessed the viability of reducing gasoline volatility as a hydrocarbon emission control measure in the South Coast Air Basin. They concluded that reductions in gasoline volatility would substantially reduce automotive evaporative emissions. Figure IV-21 shows a reasonable correlation between RVP and evaporative emissions. Furthermore, they believed that the reductions would be most substantial for uncontrolled vehicles. Some offset of these reductions due to a slight increase in exhaust emissions was also suspected. Note that in the study area, uncontrolled vehicles constitute a small percentage of the vehicle fleet.

The authors cautioned that considerable variability existed in the published literature concerning the effects of RVP on exhaust emissions.

Pidgeon (1984) studied the effects of fuel volatility on 6 vehicles which had their evaporative emission carbon cannisters removed. He also noted a report which tested the same vehicles with different RVP fuels and with their carbon cannisters installed. The difference in evaporative emissions with the two types of fuel varied considerably from vehicle to vehicle. In general, however, evaporative emissions increased when the higher RVP fuel was used.

4. Effect of RVP on Driveability

Clarke (1971) summarized the findings of three surveys which investigated the effects of fuel volatility on driveability. The first study was a survey of consumer reactions to volatility impacts on cold weather driveability. The second

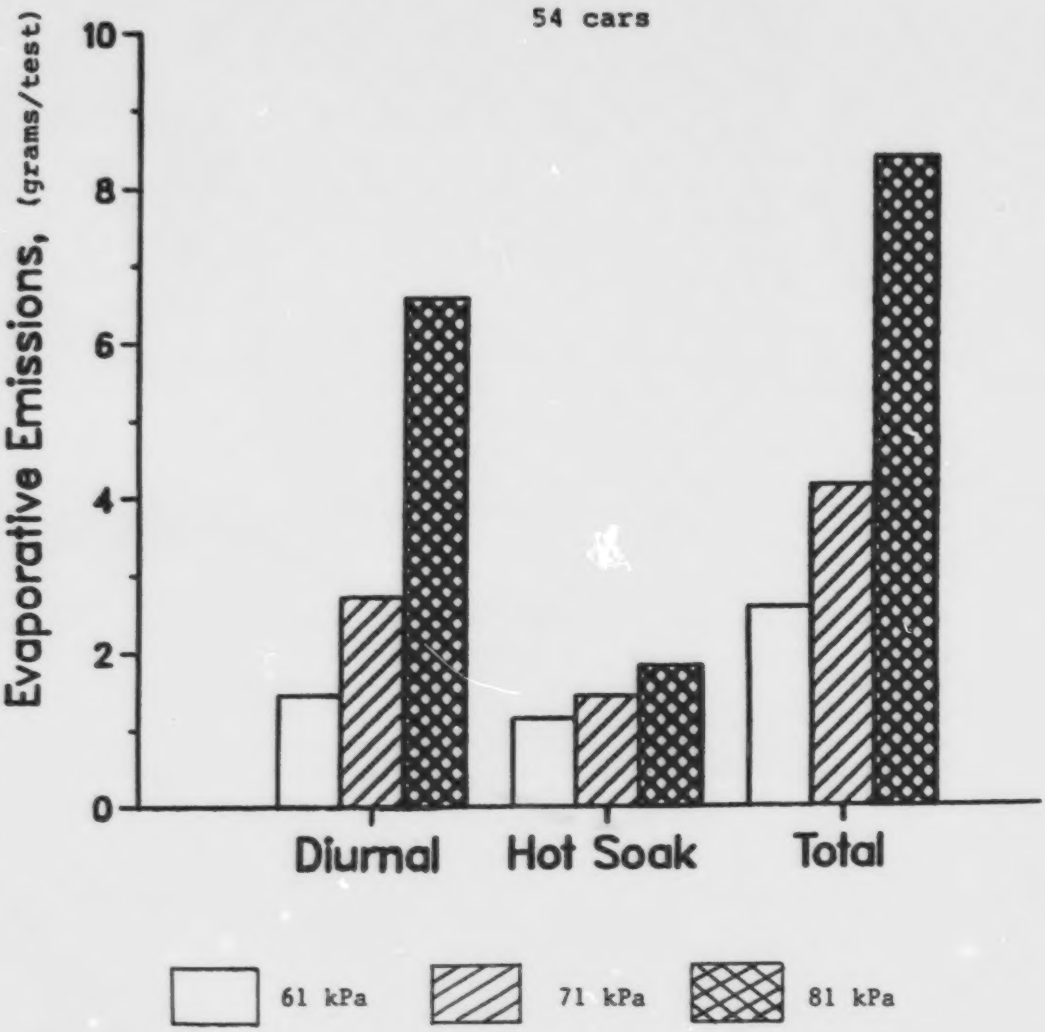


FIGURE IV-19 EFFECT OF RVP

Source: Automotive Testing Laboratories, Inc. (1986)

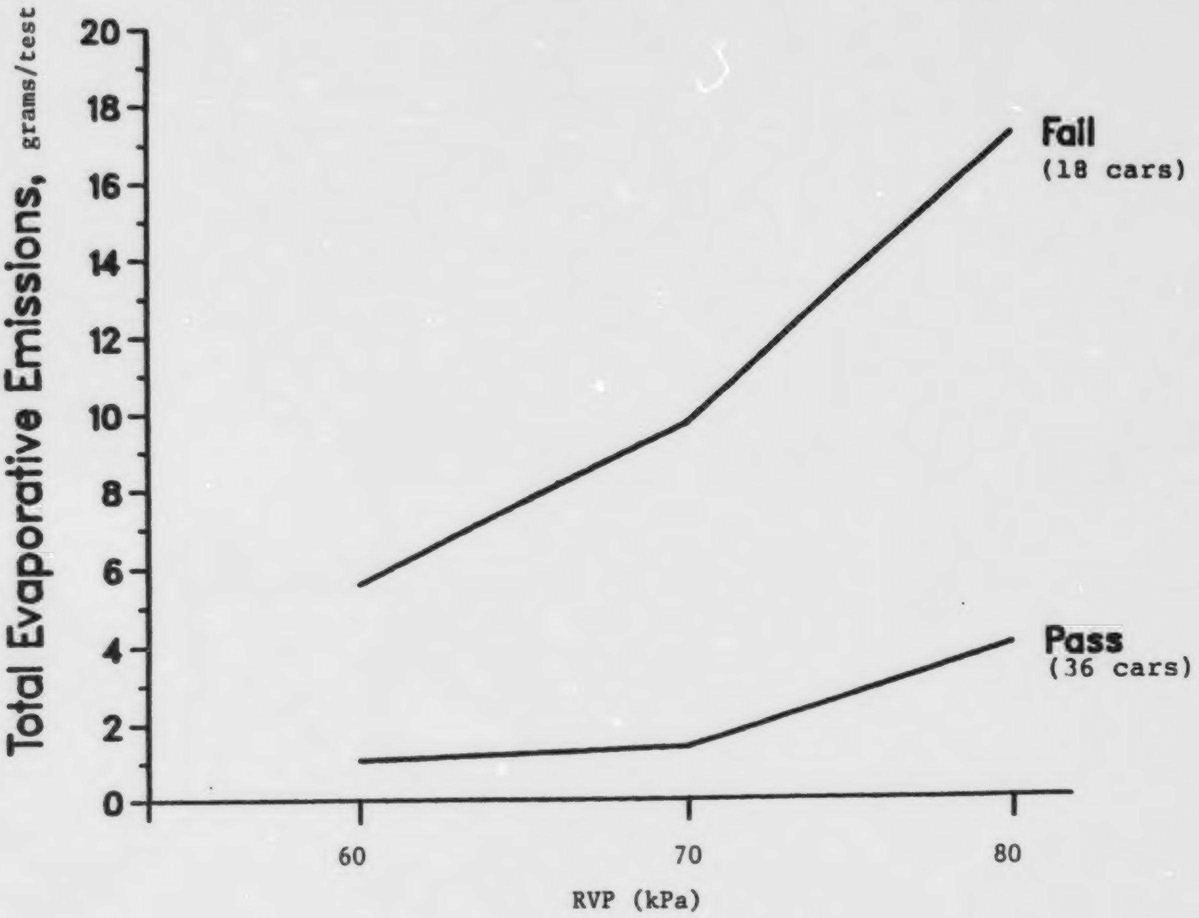


FIGURE IV-20 EFFECT OF COMPLIANCE WITH STANDARD

Source: Automotive Testing Laboratories, Inc. (1986)

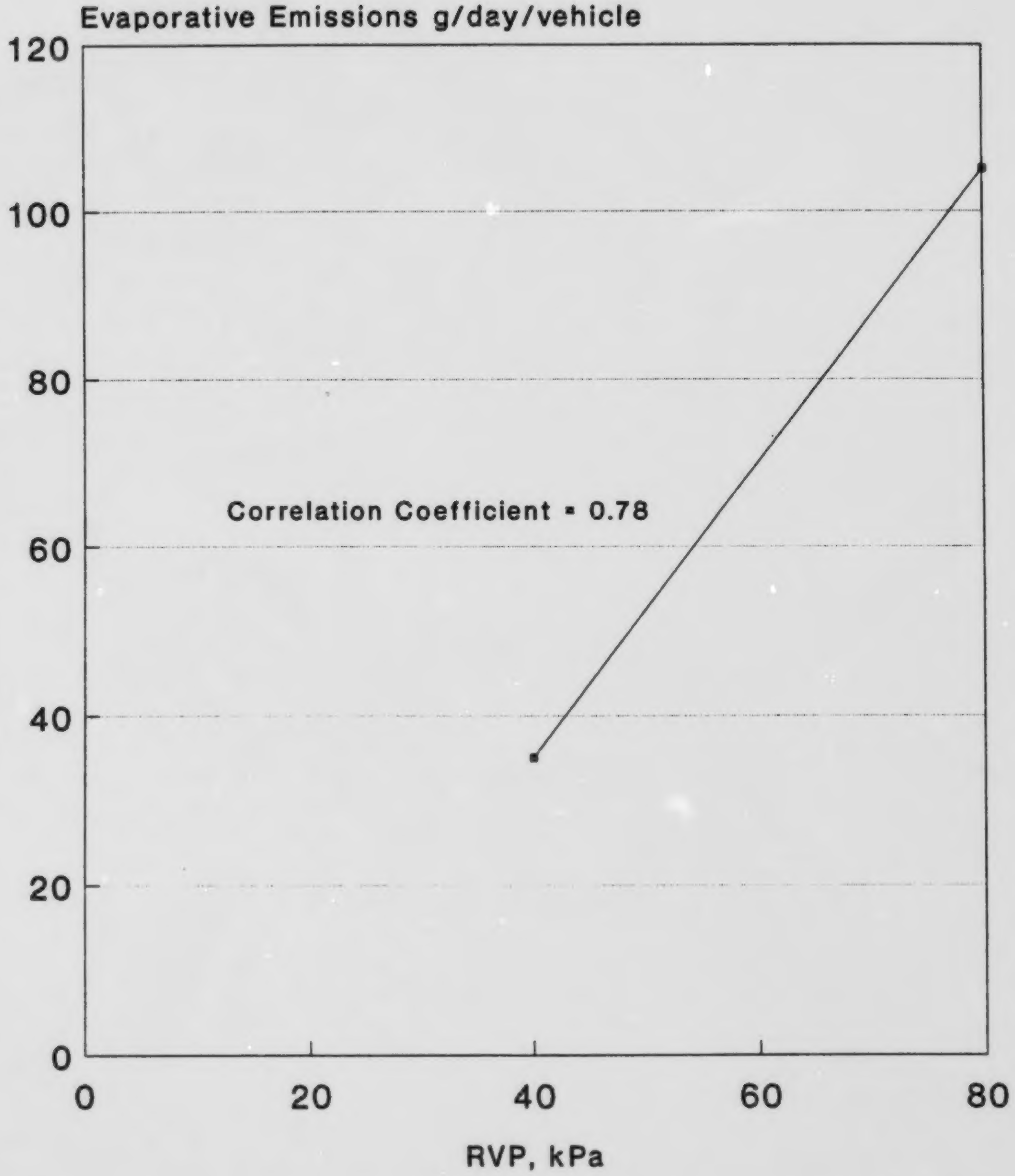


FIGURE IV-21 RVP VS AUTOMOTIVE EVAPORATIVE EMISSIONS

Source: Venturini et al (1975)

study determined the upper volatility limit which affected odour and hot starting. The last study indicated the effects of front-end volatility on exhaust emissions.

Cold weather performance is primarily affected by mid-fill and back-end volatility according to Clarke (1971).

Five fuels with RVP's ranging from 48 to 114 kPa (7 to 16.6 psi) were used in a hot start test. Start-up times were variable depending on the particular car. However, there was little difference in start-up times for all fuels.

Four different RVP fuels were used to test the effects of fuel front-end volatility on exhaust emissions. The RVP ranged from 46 to 104 kPa (6.7 to 15.1 psi). There was some reduction in exhaust emissions with higher RVP fuels according to the study. On average, about a 10% exhaust hydrocarbon reduction was realized for a 35 kPa (5 psi) increase in RVP.

The 1980 Analysis Panel of the CRC - Volatility Group (1982) reported the normalized regression coefficients showing the effect of ambient temperature on the relative importance of the distillation temperatures for the 10%, 50% and 90% evaporated fractions. RVP was not mentioned in this study, however, it is apparent that the T10 (distillation temperature for 10% evaporated) is very significant at the lower temperatures but is only slightly important at 60°F as seen in Table IV-7.

Steber et al (1985) reported on a driveability test on late model cars using fuels with RVP's of 48 kPa, 62 kPa and 76 kPa (7.0, 9.0 and 11.0 psi). An analysis of the variance on the experimental data was conducted with a 95% significance level as a cutoff. From this analysis, the authors concluded that there was no significant difference between the fuel systems studied on cold start and warm-up for late model cars.

E. Control of Toxic Emissions

Furey and Nagel (1986) studied three fuel types to determine the hydrocarbon composition emitted from a vehicle fuel tank during refueling. The fuels and RVP's were:

1. Howell 60.0 kPa (8.7 psi);
2. Indolene 61.4 kPa (8.9 psi);
3. Chevron 74.5 kPa (10.8 psi).

TABLE IV-7 NORMALIZED REGRESSION COEFFICIENTS

AMBIENT TEMPERATURE °C	T10	T50	T90
-29	0.75	0.27	0.00
-17	0.64	0.31	0.05
- 7	0.53	0.36	0.11
4	0.39	0.43	0.18
16	0.20	0.52	0.28

Source: 1980 Analysis Panel of the CRC -
Volatility Group

The fuel properties of the first two fuels are carefully controlled to meet EPA specifications as test fuel. The Chevron unleaded gasoline is widely used by automobile manufacturers for new car emissions certification testing.

The authors found that the composition of the vapours in equilibrium with liquid were strongly dependent on the liquid composition. Furthermore, the vapour composition could be satisfactorily determined from the liquid composition using ideal solution theory. The concentration of aromatics in the three fuels ranged between 29 and 39% by weight. The concentration in the vapour ranged between 2 and 4% by weight. The bulk of the vapour was composed of butanes and pentanes, primarily normal butane and normal pentane.

Seizinger et al (1986) studied the effect of benzene concentration in 69 kPa RVP gasolines on exhaust and evaporative benzene emissions. The benzene content of the fuels ranged between 0.02 to 4% by volume. The major finding was that exhaust, evaporative and tank head space benzene levels all increased linearly with increasing fuel benzene content. Figure IV-22 shows how head space, evaporative and exhaust emissions of benzene by weight percent varied with benzene volume percent in the fuel. It should be noted that the extremely poor repeatability of the evaporative emissions test as shown in Figure IV-23 was because of benzene desorption from the test vehicles' evaporative control cannisters.

Figure IV-22 shows that benzene emissions also increased with increasing aromatic content. This increase was due to increased exhaust emissions. The relative amounts of refueling, evaporative and exhaust benzene emission rates for varying benzene volume percent and aromatic volume percent is shown in Figure IV-24.

On a weight basis, benzene accounted for 1 - 3% of the evaporative HC emissions up to 2% of the refueling HC emissions, and 4 - 8% of the exhaust HC emissions.

Ames et al (1987) assumed a constant factor of 0.8 weight percent benzene in total hydrocarbon emissions from all retail service stations. They report the cost effectiveness of benzene control ranged from $ 117 US/kg to $ 183 US/kg of benzene reduced using vapour balancing and refueling emissions control at service stations.

In an earlier report, Ames et al (1986) looked at the cost effectiveness of additional controls on gasoline marketing related emissions. The cost effectiveness for controls at bulk terminals, bulk plants and service stations and for gasoline specifications of benzene content ranged between $ 42/kg and $ 117 US/kg of benzene reduced.

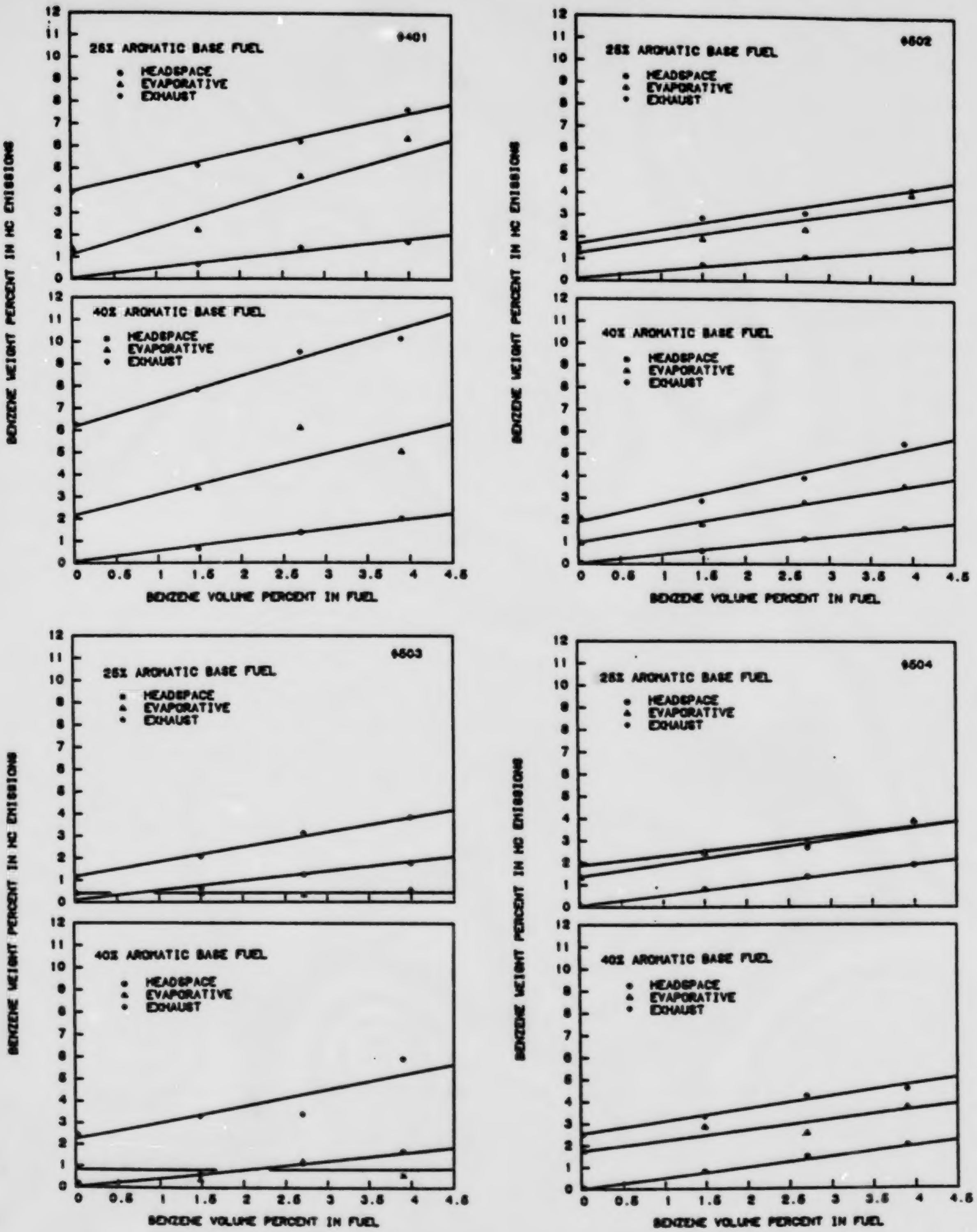


FIGURE IV-22 EVAPORATIVE AND EXHAUST AND TANK HEAD SPACE BENZENE FRACTIONS IN HC EMISSIONS VERSUS BENZENE LEVELS IN TEST FUELS. VEHICLE IDENTIFICATION NUMBER IN UPPER RIGHT-HAND CORNER OF EACH PAIR.

Source: Seizinger et al (1986)

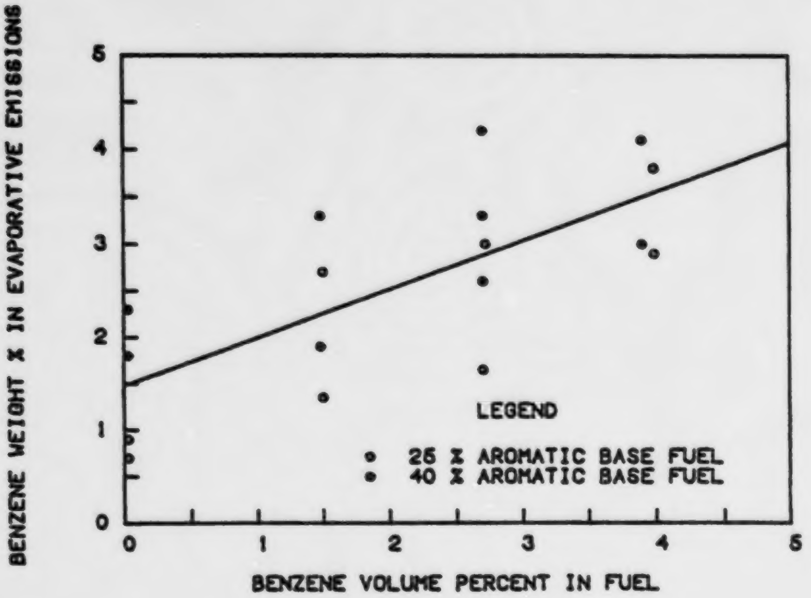


FIGURE IV-23 EFFECT OF FUEL BENZENE CONTENT ON BENZENE FRACTION OF EVAPORATIVE LOSSES (VEHICLE 501)

Source: Seizinger et al (1986)

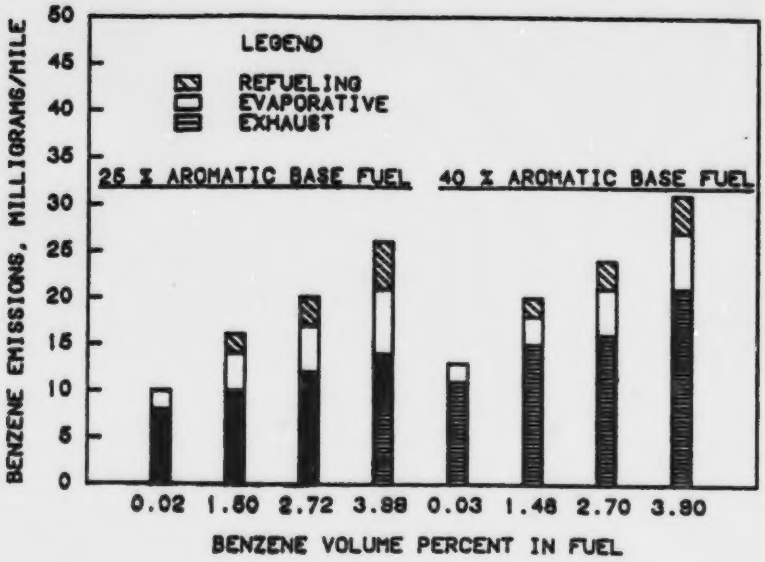


FIGURE IV-24 REFUELING, EVAPORATIVE AND EXHAUST EMISSION RATES (mg/mile)

Source: Seizinger et al (1986)

V. ESTIMATED VOC REDUCTIONS BY IMPLEMENTATION OF CONTROLS

A. Fixed Roof Tanks Larger Than 150 m^3

Four fixed roof tanks, all located at bulk terminals, were the source of 354.3 tonnes of VOC emissions in the base year. This amounts to 5.4% of the total VOC emissions from gasoline marketing in the study area.

Retrofitting of these tanks to internal floating roof tanks to control the working losses as discussed previously would reduce the base year VOC emissions by 347.0 tonnes. The remaining 7.3 tonnes of VOC emissions are attributed to standing losses. This amounts to an average reduction of 98% for all four tanks. The actual reduction for each tank depends on the throughput and diameter of the tank. Table V-1 summarizes the pertinent information.

The emissions from fixed roof tanks retrofitted with internal floating decks were assumed to be the same as the emissions from internal floating roof tanks. Emissions were estimated using the emission equations of the internal floating roof tanks. Retrofitting fixed roof tanks to internal floating roof tanks is independent of other VOC control options. In other words, the emissions from other sources are not affected by retrofitting or not retrofitting.

B. Bulk Loading Operations

The bulk loading of gasoline takes place at eight locations within the study area.

1. Truck Terminals

Loading operations at four truck terminals accounted for 1166.2 tonnes of VOC emissions in the base year. This is 17.9% of the total VOC emissions from gasoline marketing within the study area.

Installing vapour processing facilities on site at each of the terminals would reduce the base year VOC emissions by 1051.2 tonnes. The remaining 115.0 tonnes of VOC emissions are attributed to vapour collection equipment leakages - including truck tank leaks - and vapour processor emissions. This amounts to an average reduction of 90% for all four terminals. Table V-2 summarizes the pertinent information.

The loading emissions after control by vapour processing at truck terminals were estimated by assuming a vapour processor

TABLE V-1 VOC EMISSIONS REDUCTION BY RETROFITTING LARGE FIXED ROOF TANKS

TANK	DIAMETER (m)	THROUGHPUT (m^3/yr)	FIXED ROOF TANK EMISSIONS (tonnes/yr)	INTERNAL FLOATING ROOF TANK EMISSIONS (tonnes/yr)	REDUCTION IN EMISSIONS (tonnes/yr)
A	24.4	85.2	64.5	2.3	62.2
B	18.3	148.6	110.3	1.8	108.4
C	18.3	185.1	136.9	1.8	135.1
D	14.6	56.4	42.6	1.4	41.2
		475.3	354.3	7.3	347.0

TABLE V-2 VOC EMISSION REDUCTIONS AT TRUCK TERMINALS

TERMINAL	GASOLINE THROUGHPUT (m^3/yr)	UNCONTROLLED LOADING EMISSIONS (tonnes/yr)	CONTROLLED LOADING EMISSIONS (tonnes/yr)	REDUCTION IN LOADING EMISSIONS (tonnes/yr)
A	441,100.3	264.9	26.1	238.8
B	538,674.4	322.4	31.8	290.6
C	585,682.6	349.7	34.5	315.2
D	383,542.1	229.2	22.6	206.6
	1,948,998.4	1,166.2	115.0	1,051.2

discharge rate of 35 mg VOC per litre gasoline transferred and a fugitive emission rate of 4%.

Vapour processing equipment in the United States is presently designed to meet the 35 mg/L standard. Experience in the United States (Garteiser (1988) and Halbleib (1988)) has indicated that vapour processing equipment can readily meet or exceed the 35 mg/L standard.

The 4% fugitive emission rate is based on California Air Resources Board Certification tests where 96% efficiencies were achieved for vapour balancing at service stations. Actual efficiencies are a function of the tightness of valve and pump fittings. The maintenance frequency significantly affects fugitive emissions.

The control of emissions from truck loading operations is not fully independent of other control strategies. It is a stand-alone option which can be implemented even if other control strategies are not. Conversely, other control options such as vapour balancing at service stations, will affect the emissions - both controlled and uncontrolled - at the truck terminals by increasing the VOC concentration in the returned vapours.

2. Marine Terminals

Loading operations at four marine terminals accounted for 596.3 tonnes of VOC emissions in the base year. This is 9.2% of the total VOC emissions from gasoline marketing within the study area.

Installing vapour processing facilities on site at each of the terminals would reduce the base year emissions by about 440 tonnes. The remaining 156.3 tonnes of VOC emissions are attributed to vapour collection equipment leakages - including marine tank leaks - and vapour processor emissions. This amounts to an average reduction of 74% for all four terminals. Table V-3 summarizes the pertinent information.

The loading emissions after control by vapour processing at marine terminals were estimated by assuming a vapour processor discharge rate of 35 mg VOC per litre of gasoline transferred and a fugitive emission rate of 20%. This high "fugitive" emission rate reflects the fact that some barges would not be retrofitted with vapour balancing equipment due to unfavourable cost effectiveness.

Vapour processing equipment is not widely used at marine terminals in the United States at present. New regulations and

TABLE V-3 VOC EMISSION REDUCTIONS AT MARINE TERMINALS

TERMINAL	GASOLINE THROUGHPUT (m^3/yr)	UNCONTROLLED LOADING EMISSIONS (tonnes/yr)	CONTROLLED LOADING EMISSIONS (tonnes/yr)	REDUCTION IN LOADING EMISSIONS (tonnes/yr)
A	344,749.2	124.2	32.6	91.6
B	384,118.8	178.6	46.8	131.8
C	461,399.8	214.6	56.3	158.3
D	169,645.2	78.9	20.6	58.3
	1,349,913.2	596.3	156.3	440.0

increased efforts to reduce VOC emissions will require vapour processing at marine terminals in the very near future. Therefore, without the benefit of experience in the United States, it was assumed that the same discharge limit could be met for marine terminals and truck terminals. Loading rates are not very different for both types of terminals, therefore, the assumption seems reasonable. Furthermore, suppliers' price estimates were for the 35 mg/L limit.

The control of emissions from marine terminal loading operations is fully independent of other control strategies. It is a stand-alone option which can be implemented even if other control strategies are not. Furthermore, other control strategies, other than gasoline volatility reduction, will not affect the emissions - either controlled or uncontrolled - at marine terminals.

C. Fixed Roof Tanks at Bulk Plants

Forty-two fixed roof tanks located at fifteen bulk plants in the study area were the source of 67.8 tonnes/yr of VOC emissions. These emissions, primarily working losses, amount to 1.0% of the total VOC emissions from gasoline marketing in the study area.

Vapour balancing during delivery of gasoline to these tanks to control the working losses as discussed previously would reduce the base year VOC emissions by 56.7 tonnes/yr. The remaining 11.1 tonnes are attributed to standing losses and some working losses. This amounts to an average reduction of 84% of the emissions from deliveries at the 15 bulk plants. The actual reduction for each bulk plant depends on the throughputs and the number and diameter of the tanks at each plant. Table V-4 summarizes the pertinent information.

The emissions after vapour balancing were estimated to be equal to the standing losses and fugitive emissions. In other words, the working losses were asssumed to be controlled by vapour balancing. An average fugitive emission rate of 5% was applied since vapour balancing at a bulk plant is very similar to vapour balancing at service stations.

Emissions reduction was estimated for an average throughput bulk plant. The reduction percentage for the average plant was applied to all bulk plants (with above ground storage tanks) to get an overall reduction estimate.

Vapour balancing at bulk plants is dependent on VOC control at truck terminals. Vapour balancing at bulk plants will have a very small impact on emissions at truck terminals - both controlled and

TABLE V-4 VOC EMISSION REDUCTIONS AT BULK PLANTS

		UNCONTROLLED EMISSIONS			
	GASOLINE THROUGHPUT (m^3/yr)	WORKING LOSSES (tonnes/yr)	STANDING LOSSES (tonnes/yr)	CONTROLLED EMISSIONS (tonnes/yr)	REDUCTION IN EMISSIONS (tonnes/yr)
Average plant	5,422.1	4.3	0.6	0.8	4.1
Total bulk plants	98,199	59.6	8.2	11.1	56.7

uncontrolled - by increasing the concentration of vapours returned to the truck terminals.

Vapour balancing at bulk plants could be practised as an incremental reduction in VOC emissions over and above the reductions achievable by vapour processing at truck terminals alone.

D. Service Stations

The 600 automobile service stations were the source of 3,023.0 tonnes/yr of VOC emissions in the base year. This amounts to 46.4% of the total VOC emissions from gasoline marketing in the study area.

Vapour balancing during deliveries of gasoline, if practised at all stations, would reduce the base year VOC emissions by 1,420.8 tonnes. Further vehicle refueling vapour balancing would reduce the base year VOC emissions by an additional 1,065.6 tonnes for a total reduction of 2,486.4 tonnes. This amounts to average reductions of 47% and 82% of VOC emissions respectively. The actual reductions depend on the throughput, number of tanks, number of nozzles and in-use efficiencies. Table V-5 summarizes the pertinent information.

The emissions after control by vapour balancing during deliveries at service stations were estimated for two representative sizes of service stations. A vapour collection efficiency of 95% was used based on California Air Resources Board certification requirements as being readily attainable. The average in-use reduction of 47% was applied to all stations to get the overall reduction estimate.

Similarly, emissions after control by the additional measure of vehicle refueling vapour balancing were estimated for the same two service stations. A collection efficiency of 75% for the vehicle refueling vapour balance efficiency was used as an average of the values reported by Multinational Business Services, Inc. (1988). Note that actual in-use efficiencies measured throughout the United States vary widely between 48% and 92% depending, primarily, on the degree of maintenance and, hence, the degree of regulatory enforcement.

The control of emissions from service stations is dependent on vapour processing equipment operating at truck terminals. In other words, this control strategy could be viewed as an incremental reduction of emissions over and above the reduction attainable by vapour processing at truck terminals. Furthermore, the vehicle refueling vapour balancing could also be viewed as an incremental reduction of emissions over and above the reduction attainable by

TABLE V-5 VOC EMISSION REDUCTIONS AT SERVICE STATIONS

GASOLINE VEHICLE THROUGHPUT BALANCING	DELIVERY VAPOUR BALANCING			VEHICLE REFUELING VAPOUR BALANCING		DELIVERY AND REFUELING VAPOUR
(m^3/yr)	UNCONTROLLED VOC EMISSIONS (tonnes/yr)	VOC REDUCTIONS (tonnes/yr)	CONTROLLED VOC EMISSIONS (tonnes/yr)	INCREMENTAL VOC REDUCTIONS (tonnes/yr)	CONTROLLED VOC EMISSIONS (tonnes/yr)	TOTAL NET VOC REDUCTIONS (tonnes/yr)
1,395,181	3,023.0	1,420.8	1,602.2	1,065.6	536.6	2,486.4

vapour processing during deliveries. Of course, both degrees of vapour balancing could be considered together.

It is important to note that vapour balancing will increase the hydrocarbon concentration in the vapours ending up in the delivery tank trucks. Each incremental increase in concentration will increase the amount of potentially recoverable product at the truck terminals. Each incremental increase in concentration will also increase the fugitive emissions due to leakage over and above the emissions at truck terminals where vapour processing is practiced alone.

It is also important to note that the reduced emissions at service stations after vapour balancing on deliveries is practised will show up partially as a credit for recovered gasoline at the truck terminals and partially as a reduction of losses from the tank truck during deliveries at service stations. Increased hydrocarbon concentration in the delivery truck tank vapour space as a result of vapour balancing reduces the driving force for volatilization thereby reducing the product loss.

Vehicle refueling vapour balancing not only incrementally increases the amount of product potentially recoverable at truck terminals, but also reduces the loss of product from the service stations. Increased hydrocarbon concentration in the vapour space of the storage tanks as a result of vehicle refueling vapour balancing reduces the driving force for volatilization thereby reducing the product loss. This reduction in product loss is a credit to the service stations. Table V-6 illustrates the recoverable amount of potentially rcoverable product at the truck terminals and service stations for the various degrees of vapour emission control.

E. Gasoline Volatility Reduction

Gasoline volatility reduction has the potential to reduce VOC emissions arising from nearly every aspect of the gasoline marketing network in the study area. These reductions are not additive to the alternate controls examined in this study.

VOC emissions were calculated for RVP reduction cases using the data management system developed for the 1985 inventory, which contains all emission factor correlations and fuel data needed for fuel marketing sources. Because the emission factors available for VOC emissions from marine loading are constants and do not include vapour pressure as a variable the impact of decreases in fuel RVP were estimated from the correlation for emissions from trucks and rail cars. In the 1985 inventory, the emission factor for bulk users was set equal to that for service stations. This same methodology was used to determine the effect on bulk user emissions of decreasing RVP.

TABLE V-6 POTENTIALLY RECOVERABLE PRODUCT AT TRUCK TERMINALS AND SERVICE STATIONS[1]

DESCRIPTION OF CONTROL PRACTICED	POTENTIALLY RECOVERABLE PRODUCT AT:[2]			
	TRUCK TERMINAL		SERVICE STATION	
	(tonnes/yr)	(m^3/yr)	(tonnes/yr)	(m^3/yr)
Vapour processing at terminal only	1,051.6	1444	--	--
plus delivery vapour balancing at service stations	1,670.9	2295	775.3	1065
plus vehicle refueling vapour balancing at service stations	2,166.5	2976	1,324.7	1820

[1] Values are cumulative for each additional control option

[2] Density of recoverable product taken as 728 kg/m^3

Four step reductions in summertime (May to September inclusive) gasoline RVP were evaluated to establish the VOC reduction from the 1985 base that would result. The four cases assumed a maximum RVP for the five month period. Any RVP values typical of "summertime" gasoline that were lower than the maximum limits set in each case were assumed to take precedence. The four RVP limits were 79 kPa, 72 kPa, 69 kPa and 62 kPa (11.5 psi, 10.5 psi, 10 psi and 9 psi). Table V-7 lists the RVP's for each of the four cases plus the original RVP's. Table V-8 lists the total VOC emissions after applying the lower RVP levels.

F. Summary

The potential impacts on emissions by the various control strategies described previously are summarized in Table V-9.

A further breakdown for each of the aromatic compounds of concern - namely benzene, toluene and xylene - appears in Tables V-10 to V-12. Because no specific control efficiency data were available for aromatic compounds, it was assumed that the penetration of these compounds through the control system is 10% of the value for VOCs. In other words, a 90% efficiency for VOC would translate into a 99% efficiency for aromatics.

TABLE V-7 RVP's FOR ALL CASES

MONTH	BASE CASE	CASE I 79 kPa LIMIT	CASE II 72 kPa LIMIT	CASE III 69 kPa LIMIT	CASE IV 62 kPa LIMIT
January	104	104	104	104	104
February	98	98	98	98	98
March	93	93	93	93	93
April	91	91	91	91	91
May	83	79	72	69	62
June	76	76	72	69	62
July	74	74	72	69	62
August	72	72	72	69	62
September	82	79	72	69	62
October	90	90	90	90	90
November	101	101	101	101	101
December	98	98	98	98	98

All pressures in kPa

TABLE V-8 VOC EMISSIONS WITH RVP CONSTRAINTS

CASE	VOC EMISSIONS (tonnes/yr)	% REDUCTION FROM BASE CASE
Base Case	6,516.6	
Case I 79 kPa Limit	6,462.1	0.9
Case II 72 kPa Limit	6,335.1	3.1
Case III 69 kPa Limit	6,212.7	5.1
Case IV 62 kPa Limit	5,983.0	9.1

TABLE V-9 SUMMARY OF VOC EMISSIONS

CONTROL OPTION	EMISSION REDUCTION (tonnes/year)	REDUCTION[1] (%)	NET EMISSIONS[1] AFTER CONTROL (tonnes/year)
A. Fixed Roof Tanks > 150 m^3 (retrofitting to internal floating roof tanks)	347.0	5.4	6,169.6
B. Bulk Loading Operations			
1. Truck Terminals (vapour processing alone)	1,051.2	16.1	5,465.4
2. Marine Terminals (vapour processing alone)	440.0	6.8	6,076.6
C. Fixed Roof Tanks at Bulk Plants (Vapour Balancing) (incremental)	56.7	0.9	6,459.9
D. Service Stations (incremental)			
1. Vapour balancing during deliveries only	1,420.8	21.8	5,095.8
2. Vapour balancing during vehicle refueling (incremental)	1,065.6	16.4	5,451.0
3. Total	2,486.4	38.2	4,030.2
E. RVP Reduction			
79 kPa Limit	54.5	0.9	6,462.1
72 kPa Limit	181.5	3.1	6,335.1
69 kPa Limit	303.9	5.1	6,212.7
62 kPa Limit	533.6	9.1	5,983.0

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[1] Compared to base case of 6516.6 tonnes VOC.

TABLE V-9 SUMMARY OF VOC EMISSIONS (CONTINUED)

CONTROL OPTION	EMISSION REDUCTION (tonnes/year)	REDUCTION[1] (%)	NET EMISSIONS[1] AFTER CONTROL (tonnes/year)
F. Combinations			
1. Truck terminals and service station delivery vapour balancing	2,446.2	37.5	4,070.4
2. Truck terminals and service station delivery and re-fueling vapour balancing	3,491.2	53.6	3,025.4
3. Fixed roof tanks > 150 m^3 and truck terminals	1,398.2	21.5	5,118.4
4. Fixed roof tanks > 150 m^3, truck terminals and service station delivery vapour balancing	2,793.2	42.9	3,723.4
5. Fixed roof tanks > 150 m^3, truck terminals and service stations - all vapour balancing	3,838.2	58.9	2,678.4

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[1] Compared to base case of 6516.6 tonnes VOC.

TABLE V-10 SUMMARY OF BENZENE EMISSIONS

CONTROL OPTION	EMISSION REDUCTION (tonnes/year)	REDUCTION[1] (%)	NET EMISSIONS[1] AFTER CONTROL (tonnes/year)
A. Fixed Roof Tanks > 150 m^3 (retrofitting to internal floating roof tanks)	1.0	5.4	17.9
B. Bulk Loading Operations			
1. Truck Terminals (vapour processing alone)	3.2	17.0	15.7
2. Marine Terminals (vapour processing alone)	1.4	7.2	17.5
C. Fixed Roof Tanks at Bulk Plants (Vapour Balancing) (incremental)	0.17	0.9	18.7
D. Service Stations (incremental)			
1. Vapour balancing during deliveries only	4.1	21.8	14.8
2. Vapour balancing during vehicle refueling (incremental)	3.1	16.4	15.8
3. Total	7.2	38.2	11.7
E. Combinations			
1. Truck terminals and service station delivery vapour balancing	7.3	38.5	11.6
2. Truck terminals and service station delivery and refueling vapour balancing	10.4	54.8	8.5

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[1] Compared to base case of 18.9 tonnes benzene.

TABLE V-10 SUMMARY OF BENZENE EMISSIONS (CONTINUED)

CONTROL OPTION	EMISSION REDUCTION (tonnes/year)	REDUCTION[1] (%)	NET EMISSIONS[1] AFTER CONTROL (tonnes/year)
E. Combinations (continued)			
3. Fixed roof tanks > 150 m^3 and truck terminals	4.2	22.4	14.7
4. Fixed roof tanks > 150 m^3, truck terminals and service station delivery vapour balancing	8.3	43.9	10.5
5. Fixed roof tanks > 150 m^3, truck terminals and service stations - all vapour balancing	11.4	60.5	7.5

---

[1] Compared to base case of 18.9 tonnes benzene.

TABLE V-11 SUMMARY OF TOLUENE EMISSIONS

CONTROL OPTION	EMISSION REDUCTION (tonnes/year)	REDUCTION[1] (%)	NET EMISSIONS[1] AFTER CONTROL (tonnes/year)
A. Fixed Roof Tanks > 150 m^3 (retrofitting to internal floating roof tanks)	0.4	5.4	7.4
B. Bulk Loading Operations			
1. Truck Terminals (vapour processing alone)	1.3	17.0	6.5
2. Marine Terminals (vapour processing alone)	0.6	7.3	7.2
C. Fixed Roof Tanks at Bulk Plants (Vapour Balancing) (incremental)	0.07	0.9	7.7
D. Service Stations (incremental)			
1. Vapour balancing during deliveries only	1.7	21.8	6.1
2. Vapour balancing during vehicle refueling (incremental)	1.3	16.4	6.5
3. Total	3.0	38.2	4.8
E. Combinations			
1. Truck terminals and service station delivery vapour balancing	3.0	38.8	4.8
2. Truck terminals and service station delivery and refueling vapour balancing	4.3	54.8	3.5

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[1] Compared to base case of 7.8 tonnes toluene.

TABLE V-11 SUMMARY OF TOLUENE EMISSIONS (CONTINUED)

CONTROL OPTION	EMISSION REDUCTION (tonnes/year)	REDUCTION[1] (%)	NET EMISSIONS[1] AFTER CONTROL (tonnes/year)
E. Combinations (continued)			
3. Fixed roof tanks > 150 m^3 and truck terminals	1.75	22.4	6.0
4. Fixed roof tanks > 150 m^3, truck terminals and service station delivery vapour balancing	3.4	43.9	4.4
5. Fixed roof tanks > 150 m^3, truck terminals and service stations - all vapour balancing	4.7	60.5	3.1

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[1] Compared to base case of 7.8 tonnes toluene.

TABLE V-12 SUMMARY OF XYLENE EMISSIONS

CONTROL OPTION	EMISSION REDUCTION (tonnes/year)	REDUCTION[1] (%)	NET EMISSIONS[1] AFTER CONTROL (tonnes/year)
A. Fixed Roof Tanks > 150 m^3 (retrofitting to internal floating roof tanks)	0.07	5.4	1.2
B. Bulk Loading Operations			
1. Truck Terminals (vapour processing alone)	0.2	17.0	1.1
2. Marine Terminals (vapour processing alone)	0.1	7.2	1.2
C. Fixed Roof Tanks at Bulk Plants (Vapour Balancing) (incremental)	0.01	0.9	1.3
D. Service Stations (incremental)			
1. Vapour balancing during deliveries only	0.3	21.8	1.0
2. Vapour balancing during vehicle refueling (incremental)	0.2	16.4	1.1
3. Total	0.5	38.2	0.8
E. Combinations			
1. Truck terminals and service station delivery vapour balancing	0.5	38.5	0.8
2. Truck terminals and service station delivery and refueling vapour balancing	0.7	54.8	0.6

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[1] Compared to base case of 1.3 tonnes xylene

TABLE V-12 SUMMARY OF XYLENE EMISSIONS (CONTINUED)

CONTROL OPTION	EMISSION REDUCTION (tonnes/year)	REDUCTION[1] (%)	NET EMISSIONS[1] AFTER CONTROL (tonnes/year)
E. Combinations (continued)			
3. Fixed roof tanks > 150 m^3 and truck terminals	0.3	22.4	1.0
4. Fixed roof tanks > 150 m^3, truck terminals and service station delivery vapour balancing	0.6	43.9	0.7
5. Fixed roof tanks > 150 m^3, truck terminals and service stations - all vapour balancing	0.8	60.5	0.5

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[1] Compared to base case of 1.3 tonnes xylene.

VI. COST OF EMISSION CONTROL SYSTEMS

A. Assumptions and Approach to Costing

The purpose of costing the various cases and scenarios is to allow the available options for control of emissions to be ranked according to cost effectiveness. This ranking was done on a pre-tax basis. Furthermore, many simplifying assumptions were made. Therefore, the cost analysis as laid out in this section may not truly reflect the individual companies' financial situation. It will, however, give a reasonable preliminary estimate of the cost effectiveness of the various control options on an industry-wide basis within the study area.

A Discounted Cash Flow (DCF) method described by George (1988) was used to determine present value and associated cost effectiveness. This same cost methodology is commonly used by industry. It was also the choice of the South Coast Air Quality Management District in their Air Quality Management Plan (1988).

The cost of control under the Discounted Cash Flow method is determined by dividing the present value of the equipment and operating costs by the emissions reduced over the life of the equipment as follows:

$$\text{Cost of Control} = \frac{\text{Present Value}}{\text{Emissions Reduced Over the Equipment Life}}$$

The present value is determined by converting the annual operating cost into an equivalent fixed sum and then adding this sum to the capital cost. This is done according to the following formulae:

$$PV = C + A \times PVF$$

where

PV - present value
C - upfront capital outlay
A - annual operating costs (net of any off-setting recovered product value)
PVF - present value factor calculated by:

$$PVF = \frac{1 - \frac{1}{(1+r)^n}}{r}$$

where

n = equipment life
r = real interest rate calculated by:
$r = i - f$

where

i = market value interest rate
f = inflation rate

The assumptions which are common to all cases and scenarios are listed in Table VI-1.

The scheduling and timing of all projects was assumed to take place "over night" in order to simplify the calculations. No exemptions were considered as a further simplification.

The capital and operating costs and value of recovered product for each of five cases are reported in Section VI-B. Included in the capital costs are those for site preparation, foundations, vapour collection system, gasoline and fuel supply and return lines, labour and materials for equipment installation, vapour processing equipment and a 10% contingency. The cost of installation labour and materials was estimated by Lorne W. Knowles and Associates Ltd., mechanical cost estimators. The cases covered are listed in Table VI-2. The cost effectiveness reported for each case assumes a stand-alone basis even though in actual fact, the control options are often intimately related. This was done only to illustrate the costs for each segment of the industry or for each type of control option. Engineering costs were based on multiple units being done.

The cost effectiveness under five possible scenarios is reported in Section VI-C. The scenarios covered are also listed in Table VI-2. The scenarios were developed on an industry-wide basis and do not reflect the costs which might be borne by an individual company. Here the costs for an entire segment of the industry were estimated from the costs reported in Section VI-B for individual cases.

A literature review of the costs and cost effectiveness of gasoline volatility control in the United States is presented in Section VI-D.

B. Capital and Operating Costs and Value of Recovered Product

1. Fixed Roof Tanks Larger Than 150 m^3

The cost estimates for retrofitting fixed roof tanks to internal floating roof tanks were provided by Horton CBI Limited

TABLE VI-1 ASSUMPTIONS USED IN COSTING

Interest rate (market value, i)	14
Inflation rate (f)	5
Interest rate (real, r) = (i-f)	9%
Equipment life (n) (except where noted as otherwise)	10 years
Present value factor for annual costs	6.4
Electricity	0.05
Natural gas	$ 3.50/GJ
Labour rate (including fringes, benefits, supervision, overhead, etc.)	$ 25.00/hour
Taxes, insurance	1.5% of capital
Engineering and permitting	8% of capital
Recovered product density	728 kg/m^3
Value of recovered product	$ 0.28/L

TABLE VI-2 CASES AND SCENARIOS INVESTIGATED

A.	Cases	
1.	Fixed Roof Tanks > 150 m^3	1 size
2.	Truck Terminals - 3 control strategies	2 sizes
3.	Bulk Plants	1 size
4.	Service Stations	2 sizes
	- 2 configurations/size - vapour balancing during deliveries - vapour balancing during deliveries and vehicle refueling	
B.	Scenarios	
1.	Fixed Roof Tanks > 150 m^3	4 tanks
2.	Truck Terminals	4 terminals
3.	Truck Terminals + Delivery Vapour Balancing at service stations	4 terminals + 600 stations
4.	Truck Terminals + Delivery Vapour Balancing + Vehicle Refueling Vapour Balancing at service stations	4 terminals + 600 stations
5.	Scenario # 4 + Fixed Roof Tanks > 150 m^3 + Bulk Plants	4 terminals + 4 tanks + 600 stations + 15 bulk plants

of Alberta. Their estimate was for supplying and installing a steel pan inside a fixed roof tank at a Lower Mainland location. Cost of primary seals and all accessories were included.

The welded steel pan is more expensive than other options according to Horton CBI Ltd. Other estimates by Dillingham Construction Ltd. and Esso Petroleum Canada were only 60% of the Horton values, although these were only "rule-of-thumb" costs. Still the costs used here are expected to be conservative or "upper-end" estimates.

Table VI-3 lists the costs, throughputs, emissions reductions, value of recovered product and diameters of each tank in this category. The equivalent volume of recovered product was estimated on the basis of typical gasoline densities of 728 kg/m^3. This is the same density as used in the data base for calculating emissions which is high considering that most of the recovered product would consist of lighter ends such as butanes and pentanes. It does, however, provide a more conservative estimate of the quantity of recoverable gasoline. The value of controlled product (emissions) was calculated based on a price of $ 0.28/litre. These values are also reported in Table VI-3.

Operating costs have been allowed for maintenance of seals and for insurance and taxes.

Cost effectiveness for tank B is used to illustrate the discounted cash flow method. The calculations which are shown in Table VI-4 show that the cost per tonne is a negative number. This indicates that retrofitting that tank to an internal floating roof tank would pay for itself within the life of the equipment - in this case within 10 years. Note that this is on a pre-tax basis.

2. Truck Terminals

Two generic terminals were evaluated for equipping truck terminals with vapour processing systems. For each terminal, two or three different control options were costed for a total of five cases. Estimates of equipment costs were supplied by manufacturers. Table VI-5 lists the sources of cost date for equipment.

The cost of retrofitting truck fleets was included in the capital costs for the truck terminal case. Retrofitting costs for different tank trucks were supplied by Columbia Remtek and Dover Corp. An average cost per truck was developed based on information about the type and number of trucks in one company's fleet. An assumption was made that 15 and 20 trucks served the low and high throughput generic terminals respectively.

TABLE VI-3 FIXED ROOF TANKS > 150 m^3 - COSTS

TANK	DIAMETER (m)	GASOLINE THROUGHPUT (m^3/yr)	EMISSION REDUCTION (tonnes/yr)	VOLUME OF RECOVERED PRODUCT (m^3/yr)	VALUE OF RECOVERED PRODUCT[1] ($/yr)	CAPITAL COST ($)
A	24.4	53,260	62.2	85.2	23,900	134,000
B	18.3	128,400	108.5	148.6	41,600	95,000
C	18.3	218,340	135.1	185.1	51,800	95,000
D	14.6	36,790	41.2	56.4	15,800	80,000
		436,790	347.0	475.3	133,100	404,000

[1] at $ 0.28/litre

TABLE VI-4 COST EFFECTIVENSS - FIXED ROOF TANKS > 150 m^3

Capital Cost (C)	$ 95,000
Operating Cost (A_1)	
Maintenance @ 1.0%	950
Taxes and insurance	1,425
	2,375
Annual Value of Recovered Product (A_2)	$ 41,600
Net Annual Charge (Credit)	$(39,225)
Annual Reduction in Emissions (E)	108.5 tonnes

Cost Effectiveness $= \frac{C-(PVF \times A)}{10 \times E}$

$$= \frac{\$\ 95,000-(6.4 \times \$\ 39,225)}{10 \times 108.5 \text{ tonnes}} = \$\ -140/\text{tonne}$$

TABLE VI-5 SUPPLIER PROVIDING COST INFORMATION

PROCESS	SUPPLIER/MANUFACTURER
Carbon Adsorption/Absorption	John Zink Company, Inc. McGill Americas, Inc.
Refrigeration	Edwards Engineering, Ltd.
Thermal Oxidation	Hirt Combustion Engineers

The impact of diesel, loaded at the racks where the vapour collection system is to be installed was expected to be very small. Therefore, it was not taken into account in this evaluation.

All estimates of equipment costs were based on vapour processing systems designed to meet or exceed a limit of 35 mg of hydrocarbon discharged from the vapour processing unit per litre of gasoline transferred at the terminal. This gives a common basis for comparison. Table VI-6 lists the capital costs for each case. The operating costs for each case are listed in Table VI-7 together with estimates of the value of recovered product. The cost effectiveness for each case is shown in Table VI-8. The results show that carbon adsorption/absorption is the most cost effective control option. The cost effectiveness is improved for the higher throughput terminal.

3. Bulk Plants

The installed capital cost for retrofitting an existing bulk plant with vapour balancing equipment is given in Table VI-9. Increased operating costs and the value of recovered product are reported in Table VI-10. Retrofitting costs included material and pipe fitting charges to connect three gasoline tanks by a manifold system which would return vapours to the point of fuel delivery. All necessary pressure/vacuum vents, check valves and condensate traps were included.

The results for cost effectiveness (Table VI-11) show that vapour balancing at a bulk plant is as cost effective as vapour processing at bulk terminals. This is so because 100% of the recovered product was credited to the plant.

TABLE VI-6 CAPITAL COSTS FOR TRUCK TERMINAL CASES

	CARBON ADSORPTION/ ABSORPTION		REFRIGERATION		THERMAL OXIDATION
Throughput (m^3/yr)	400,000	600,000	400,000	600,000	400,000
Vapour processing unit equipment and installation	379,000	464,800	546,700	585,300	210,800
Liquid supply and return lines	39,800	39,800	22,600	22,600	20,300
Vapour collection system	24,900	24,900	24,900	24,900	24,900
Foundation, assembly, etc.	22,000	22,000	16,000	16,000	30,500
Sub-Total	465,700	551,500	610,200	648,800	286,500
Engineering and permitting	37,200	44,100	48,800	51,900	22,900
Sub-Total	503,000	595,600	659,000	700,700	309,400
Cost of retrofitting trucks[1]	93,000	124,000	93,000	124,000	93,000
Total	596,000	719,600	752,000	824,700	402,400

[1] This is based on 15 trucks for the 400,000 m^3/yr terminal and 20 trucks for the 600,000 m^3/yr terminal.

TABLE VI-7 ANNUAL OPERATING COSTS FOR TRUCK TERMINAL CASES

	CARBON ADSORPTION/ ABSORPTION		REFRIGERATION		THERMAL OXIDATION
Annual throughput (m^3/yr)	400,000	600,000	400,000	600,000	400,000
Energy consumption basis	0.2 kWh/m^3	0.2 kWh/m^3	0.4 kWh/m^3	0.4 kWh/m^3	0.4 GJ/h
Energy consumption	80,000 kWh	120,000 kWh	160,000 kWh	240,000 kWh	3500 GJ
Energy cost	$ 4,000	$ 6,000	$ 8,000	$ 12,000	$ 12,300
Maintenance costs basis (% of capital)	3%	3%	4%	4%	5%
Capital cost	$ 379,000	$ 464,800	$ 546,700	$ 585,300	$ 210,800
Maintenance	$ 11,400	$ 13,900	$ 21,900	$ 23,400	$ 10,500
Manpower	185 hours	185 hours	included in maintenance costs	included in maintenance costs	included in maintenance costs
Manpower cost	$ 4,600	$ 4,600			
Taxes and insurance	$ 6,980	$ 8,270	$ 9,150	$ 9,700	$ 4,300
Total operating costs	$ 26,980	$ 32,770	$ 39,050	$ 45,100	$ 27,100
Emission reduction (tonnes)	210	315	210	315	210
Recovered product (m^3/yr)	290	430	290	430	--
Value of recovered product	$ 80,000	$ 120,000	$ 80,000	$ 120,000	--

TABLE VI-8 COST EFFECTIVENESS - TRUCK TERMINAL

	CARBON ADSORPTION/ ABSORPTION		REFRIGERATION		THERMAL OXIDATION
Throughput (m^3/yr)	400,000	600,000	400,000	600,000	400,000
Capital Cost (C) ($)	596,000	719,600	752,000	824,700	402,400
Operating Costs (A_1) ($)	26,900	32,770	39,050	45,100	27,100
Value of Recovered Product ($-A_2$) ($)	80,000	120,000	80,000	120,000	--
Net annual charge (credit) (A_1-A_2) ($)	(53,100)	(87,230)	(40,950)	(74,900)	27,100
Annual reduction in emissions (tonnes)	210	315	210	315	210
Cost effectiveness ($/tonne)	120	50	230	110	270

TABLE VI-9 BULK PLANT CAPITAL COSTS

Annual throughput	5,420 m^3
Material cost	$ 5,100
Installation cost	$ 8,900
	$ 14,000
Engineering and permitting	1,400
Total cost	$ 15,400

TABLE VI-10 BULK PLANT OPERATING COSTS

Operating Costs:	
Maintenance (incremental) 2% of capital	$ 320
Taxes and insurance	$ 80
	$ 400
Emission reduction	4.1 tonnes
Equivalent volume of fuel	5.6 m^3
Value of fuel	$ 1580

TABLE VI-11 COST EFFECTIVENESS - BULK PLANTS

Capital cost (C)	$ 15,400
Operating cost (A_1)	$ 400
Value of recovered product ($-A_2$)	$ 1,580
Net annual charge (credit) (A) (A_1-A_2)	$ (1,180)
Annual reduction in emissions	4.1 tonnes
Cost effectiveness	$ 190/tonne

4. Service Stations

Two size stations with two different configurations for a total of four cases were investigated. Capital costs of installed equipment are reported in Table VI-12.

Increased operating expenses would largely arise from the need to replace or service worn nozzles, bellows, boots and torn hoses. Standard gasoline service station equipment also requires routine servicing so it was assumed that additional costs incurred other than the type mentioned would be limited to 1% of the installed capital. All applicable increased operating costs are reported in Table VI-13.

The cost effectiveness is illustrated in Table VI-14. The results show that the vapour balancing during deliveries for the two size stations is about as cost effective as vapour balancing at a bulk plant. Vapour balancing during vehicle refueling, on the other hand, is about an order of magnitude more costly than any other control option investigated on an incremental basis. Even when combined with vapour balancing during deliveries, the cost of vapour control at service stations is at least several times the cost of vapour balancing at the bulk terminals.

5. Marine Terminals

Cost estimates for vapour processing systems were supplied by manufacturers of the equipment. Unlike truck terminals, vapour control at marine terminals is relatively new in the United States. Therefore, no reliable operating cost information was available from industry. Reasonable estimates could be made based on supplier specifications. The real shortcoming is the cost of retrofitting barges and tankers for vapour recovery. Marine vessels - even the simplest ones - are very complex and, therefore, costly to retrofit in comparison to trucks. The variety of vessels made it impossible to make reasonable retrofitting cost estimates.

The increased costs and lower throughputs are likely to make vapour processing at marine terminals an order of magnitude less cost effective than vapour processing at truck terminals.

C. Cost Effectiveness of Control Scenarios

For each of the five scenarios discussed earlier, all controllable sources within the industry have been evaluated. In order to do this, capital and operating costs for individual cases have been extrapolated to cover the entire industry. The assumptions made in extrapolating will be discussed under each scenario.

TABLE VI-12 CAPITAL COSTS - SERVICE STATIONS

	CASE I	CASE II	CASE I	CASE II
Annual throughput (m^3/yr)	2,000	2,000	4,000	4,000
Number of tanks	3	3	3	3
Number of islands	2	2	2	3
Number of nozzles	8	12	12	16
A. Vapour Balancing During Deliveries				
Capital cost per tank includes materials, pipefitting, trenching, etc.	3,000	3,000	3,000	3,000
Capital cost	9,000	9,000	9,000	9,000
Engineering and permitting	700	700	700	700
Total capital cost	$ 9,700	$ 9,700	$ 9,700	$ 9,700
B. Vapour Balancing During Vehicle Refueling (incremental)				
Nozzles, swivels, hoses and piping	23,000	31,700	31,700	40,400
Excavation, trenching, paving	7,800	8,100	8,100	8,400
Sub-total	31,800	39,800	39,800	48,800
Engineering and permitting	2,500	3,200	3,200	3,900
Total capital cost	$ 34,300	$ 43,000	$ 43,000	$ 52,700
C. Vapour Balancing During Deliveries and Vehicle Refueling				
Total Capital Cost	$ 44,000	$ 52,700	$ 52,700	$ 62,400

TABLE VI-13 OPERATING COSTS - SERVICE STATIONS

	CASE I	CASE II	CASE I	CASE II
Annual throughput (m^3/yr)	2,000	2,000	4,000	4,000
A. Vapour Balancing During Deliveries				
Increased operating costs @ 1% of capital	100	100	100	100
Taxes and insurance	150	150	150	150
Total operating costs	250	250	250	250
Emission reduction (tonnes)	2.0	2.0	4.1	4.1
Equivalent fuel volume (m^3/yr)	2.8	2.8	5.6	5.6
Value of fuel	790	790	1,570	1,570
Net annual charges (credit)	$ (540)	$ (540)	$ (1320)	$ (1320)
B. Vapour Balancing During Vehicle Refueling (incremental)				
Increased operating costs @ 1% of capital	340	430	430	530
Taxes and insurance	510	650	650	800
Replacement or repair of nozzles and hoses	2,400	3,600	3,600	4,800
Total operating costs	$ 3,250	$ 4,680	$ 4,680	$ 6,130

TABLE VI-13 OPERATING COSTS - SERVICE STATIONS (CONTINUED)

	CASE I	CASE II	CASE I	CASE II
B. Vapour Balancing During Vehicle Refueling (incremental) - (continued)				
Emission reduction (incremental)	1.7	1.7	3.4	3.4
Equivalent fuel volume (m^3/yr)	2.3	2.3	4.6	4.6
Value of fuel	650	650	1,300	1,300
Net annual charges (credit)	$ 2,600	$ 4,030	$ 3,380	$ 4,830
C. Vapour Balancing During Deliveries and Vehicle Refueling				
Net Annual Charges (credit)	$ 2,060	$ 3,490	$ 2,060	$ 3,510

TABLE VI-14 COST EFFECTIVENESS - SERVICE STATIONS

	CASE I	CASE II	CASE I	CASE II
Annual throughput (m^3/yr)	2,000	2,000	4,000	4,000
A. Vapour Balancing During Deliveries				
Capital cost (C) ($)	9,700	9,700	9,700	9,700
Net annual charge (credit) (A) ($)	(540)	(540)	(1320)	(1320)
Annual reduction in emissions (tonnes)	2.0	2.0	4.1	4.1
Cost effectivenss ($/tonne)	310	310	30	30
B. Vapour Balancing During Vehicle Refueling (incremental)				
Capital cost (C) ($)	34,300	43,000	43,000	52,700
Net annual charge (credit) (A) ($)	2,600	4,030	3,380	4,830
Annual reduction in emissions (tonnes)	1.7	1.7	3.4	3.4
Cost effectiveness ($/tonne)	3,000	4,050	1,900	2,460
C. Vapour Balancing During Deliveries and Vehicle Refueling				
Capital cost (C) ($)	44,000	52,700	52,700	62,400
Net annual charge (credit) (A) ($)	2,060	3,490	2,060	3,510
Annual reduction in emissions (tonnes)	3.7	3.7	7.5	7.5
Cost effectivenss ($/tonne)	1,550	2,030	880	1,130

1. Scenario I - Fixed Roof Tanks

Scenario I covers the retrofitting of fixed roof tanks larger than 150 m^3 to internal floating roof tanks. In the study area, there are four tanks which fit into this category.

The cost effectiveness for Scenario I is calculated in Table VI-15. The negative value indicates the controls would pay out over the 10 year life.

2. Scenario II - Truck Terminals

Scenario II covers vapour processing at all four truck terminals within the study area. Only the most cost effective process - carbon adsorption/absorption - is considered.

The capital costs in Table VI-6 for the low and high throughput cases represent the extremes of costs expected to be encountered at the study area terminals. The arithmetic average of this cost multiplied by four will be used as the total cost for installing a vapour collection system and carbon adsorption/absorption unit at all four terminals. Operating costs for the two extreme cases reported in Table VI-7 were used to calculate the total operating costs for all four terminals in the same fashion as the capital costs were determined. Emission reductions and recovered product quantities were taken from Table V-2 and Table V-6.

The cost effectiveness for Scenario II is calculated in Table VI-16.

3. Scenario III - Terminals and Service Station Deliveries

Scenario III assumes all truck terminals are equipped with vapour recovery facilities - carbon adsorption/absorption - and all service stations equipped for vapour balancing during deliveries.

Capital costs were estimated for truck terminals as discussed in Scenario II. Similarly, the cost for equipping the 600 service stations with vapour balancing equipment was estimated by averaging the cost of retrofitting the three different service station configurations and multiplying by 600. Operating costs were estimated in the same fashion as the capital costs. The reduction in emissions was taken from Tables V-5 and V-9. The quantity of recovered product was taken from Table V-6. Note that the reductions in emissions for the truck terminals are lower than in the stand-alone case (Scenario II) because of increased fugitive emissions associated with this combination.

TABLE VI-15 COST EFFECTIVENESS - SCENARIO I - FIXED ROOF TANKS

Capital cost (C)	\$ 404,000
Annual operating cost (A_1)	10,100
Emission reduction (tonnes/yr)	347.0
Equivalent volume of recovered product	475.3 m^3
Value of recovered product ($-A_2$)	\$ (133,100)
Net annual charge (credit) (A_1-A_2)	\$ (122,900)
Cost effectiveness	\$ -110/tonne

TABLE VI-16 COST EFFECTIVENESS - SCENARIO II - TRUCK TERMINALS

Capital cost (C)	\$ 2,631,200
Annual operating cost (A_1)	\$ 119,500
Emission reduction	1051.2 tonnes
Equivalent volume of recovered product	1444 m^3
Value of recovered product ($-A_2$)	\$ (404,300)
Net annual charge (credit) (A_1-A_2)	\$ (284,800)
Cost effectiveness	\$ 80/tonne

The cost effectiveness for Scenario III is illustrated in Table VI-17.

4. Scenario IV - Terminals and All Service Station Balancing

Scenario IV assumes all truck terminals equipped with vapour recovery facilities - carbon adsorption/absorption - and all service stations equipped for both delivery and vehicle refueling vapour balancing.

Capital and operating costs were taken from Scenario III for truck terminals and service station vapour balancing during deliveries. Additional costs for service station vapour balancing during vehicle refueling were taken from Tables VI-12 and VI-13. The cost for all 600 stations was estimated by taking the average of the three station configurations and multiplying by 600 as described in Scenario III. The reduction in emissions was taken from Tables V-5 and V-9. The quantity of recovered product was taken from Table V-6. Again the reduction in emissions for the truck terminals was lower than in the other scenarios because of increased fugitive emissions associated with this combination.

Cost effectiveness for Scenario IV is illustrated in Table VI-18.

5. Scenario V - Scenario IV and Tanks and Bulk Plants

Scenario V is a combination of all of the vapour control strategies previously analyzed.

Capital and operating costs, emission reductions and value of recovered product were taken from Scenarios I and IV. Additional information for bulk plants was taken from Tables VI-9, VI-10 and VI-11. The cost, emission reduction and value of recovered product for the one bulk plant was multiplied by 15 to get the total costs for all bulk plants with above-ground tanks. Cost effectiveness for Scenario V is calculated in Table VI-19.

6. Discussion of Results

Cost effectiveness of all control options was significantly influenced by the price assigned to the gasoline vapour recovered as liquid. The relative ranking of the various strategies would not change significantly by changing the price of gasoline. The relative magnitude of the values, however, could change by a factor of 10 depending on how close the present value of recovered gasoline was to the present value of capital and operating costs.

TABLE VI-17 COST EFFECTIVENESS - SCENARIO III - TERMINALS AND SERVICE STATION DELIVERIES

Capital costs	
terminals	$ 2,631,200
service stations	$ 5,820,000
Total capital cost	$ 8,451,200
Operating costs	
terminals	$ 119,500
service stations	$ 150,000
Total operating costs	$ 269,500
Equivalent volume of recovered product	
truck terminal	2,295 (m^3)
service stations	1,065 (m^3)
total	3,360 (m^3)
Value of recovered product	
truck terminal	$ 642,600
service station	$ 298,200
total	$ 940,800
Net annual charge (credit)	
truck terminal	$ (523,100)
service station	$ (148,200)
total	$ (671,300)
Emission reduction	
truck terminal	1,025.4 tonnes
service stations	1,420.8 tonnes
total	2,446.2 tonnes
Cost effectiveness	
truck terminals	$ -70/tonne
service stations	$ 340/tonne
total	$ 170/tonne

TABLE VI-18 COST EFFECTIVENESS - SCENARIO IV

Capital cost	
truck terminals	$ 2,631,200
service station	
delivery vapour balancing	$ 5,820,000
vehicle vapour balancing	$ 26,000,000
sub-total	$ 31,820,000
Total capital cost	$ 34,451,200
Operating cost	
truck terminals	$ 119,500
service stations	
delivery vapour balancing	$ 150,000
vehicle vapour balancing	$ 2,812,000
sub-total	$ 2,962,000
Total operating cost	$ 3,081,500
Equivalent volume of recovered product	
truck terminals	2,980 m^3
service stations	
delivery vapour balancing	1,065 m^3
vehicle vapour balancing	755 m^3
sub-total service station	1,820 m^3
Total volume of recovered product	4,800 m^3
Value of recovered product	
truck terminal	$ (834,400)
service station	
delivery vapour balancing	$ (298,200)
vehicle vapour balancing	$ (211,400)
sub-total	$ (509,600)
Total value of recovered product	$ (1,344,000)
Net annual charge (credit)	
truck terminal	$ (714,900)
service station	
delivery vapour balancing	$ (148,200)
vehicle vapour balancing	$ 2,600,600
sub-total	$ 2,452,400
Total net annual charge (credit)	$ 1,737,500

TABLE VI-18 COST EFFECTIVENESS - SCENARIO IV (CONTINUED)

Emission reduction	
truck terminal	1,004.8 tonnes
service station	
delivery vapour balancing	1,420.8 tonnes
vehicle vapour balancing	1,065.6 tonnes
sub-total	2,486.4 tonnes
Total Scenario IV	3,491.2 tonnes
Cost effectiveness	
truck terminal	$ -190/tonne
service station	
delivery vapour balancing	$ 340/tonne
vehicle vapour balancing	$ 4,000/tonne
combined vapour balancing	$ 1,910/tonne
Total	$ 1,300/tonne

TABLE VI-19 COST EFFECTIVENESS - SCENARIO V

Capital costs (C)	\$ 35,086,200
Operating costs (A_1)	\$ 3,367,100
Value of recovered product ($-A_2$)	\$ (1,488,950)
Net annual charge (credit) (A_1-A_2)	\$ 1,878,150
Emission reduction	3,894.9 tonnes
Cost effectiveness of Scenario V	\$ 1,210/tonne

Cost effectiveness was also strongly affected by throughput. Increased throughput leads to increased emission reductions and also increased value of recovered product. This increases the cost effectiveness by reducing the present value cost of the strategy. Cost effectivenss is also increased when the present value is divided by a higher emissions reduction. Furthermore, increased throughput does not usually lead to a proportional increase in present value costs.

To a lesser degree, cost effectiveness was also impacted by the real interest rate. Differences in interest rates of 3 percentage points only change the present value factor by 15%. In most cases, this would only have a very slight affect on cost effectiveness.

Based on the assumed values in this evaluation, the cost effectiveness ranged between -$ 140/tonne for retrofitting a fixed roof tank to $ 4,000/tonne for service station vehicle refueling vapour balancing on an incremental basis.

After fixed roof tanks, the next most cost effective measure was to equip the truck terminals with vapour control equipment. Capital and operating costs for thermal oxidation systems were the lowest, followed by carbon adsorption-absorption and then refrigeration. However, when including the credit for vapour recovery from carbon adsorption-absorption and refrigeration systems in the overall analysis, these systems were more cost effective than thermal oxidation systems. Carbon adsorption-absorption was the more cost effective system. The cost effectiveness, which depends on throughput, ranged from $ 120/tonne to $ 270/tonne for the low throughput case and $ 50/tonne and $ 230/tonne for the high throughput case.

Individually, VOC control at bulk plants and service stations during deliveries was as cost effective as control at truck terminals. Cost effectiveness at the service stations individually, ranged from $ 30/tonne to $ 300/tonne for the 4000 m^3/yr and 2000 m^3/yr throughput stations respectively. Cost effectiveness at one bulk plant was $ 190/tonne.

Collectively (Scenario III and IV), the incremental cost of vapour balancing during deliveries at service stations was $ 340/tonne. This value was higher than the individual estimates for two reasons. First, the average throughput for all 600 stations was about 2300 m^3. Second, 100% of the recovered product was credited to the service station in the individual case but only about 55% was credited to the service stations in the combined scenario. The latter was determined as the difference between the emissions reduction and the amount which could be attributed to the truck terminal as a result of higher hydrocarbon concentration in the returned vapours.

The incremental cost of vapour balancing at service stations during vehicle refueling was the least cost effective option evaluated. Individual costs varied between 1900/tonne to 4050/tonne at the 4000 m^3/yr and 2000 m^3/yr throughput stations respectively. Collectively, the incremental cost (Scenario IV), was $ 4,000/tonne. Again this was at the high end of the individual cases largely due to the fact that the average throughput is only 2300 m^3/yr.

The combined cost of vapour recovery by carbon adsorption at all truck terminals plus vapour balancing at all service stations (Scenario III), was $ 170/tonne. This is only slightly more costly than the $ 80/tonne for truck terminals alone (Scenario II). When vapour balancing during vehicle refueling is added, however, the cost jumps to $ 1,300/tonne. Cost effectiveness (Scenario V) is $ 1,200/tonne when controls are applied across the marketing network.

D. Cost of RVP Reduction

Many studies have been made of the cost of RVP reduction. The following discussion summarizes some of this material to put this control option in perspective with regard to others that are available. The reader is cautioned that the references reviewed often did not state clearly the cost estimating assumptions used or the basis for presenting the cost results.

The operating or process modifications necessary to enable refiners to reduce RVP levels depends on the individual refinery design and capacity. Likewise, the cost of reducing RVP will vary from refinery to refinery. Of course, the degree of RVP reduction required will also dictate the extent of operation and/or process modifications necessary and, hence, the ultimate cost.

The refining and gas processing industries would directly bear the cost of RVP reduction. Fasullo (1988) earlier noted the potentially negative impact on the gas processing industry if nationwide gasoline volatility reductions were implemented in the United States. Based on oil prices of $ 138 US/m^3 crude, the fuel value of butane was estimated to be about 40% less than its gasoline blending value. Assuming that the backed-out butanes would mostly be priced at fuel value since few alternatives exist other than to use butane as fuel, Fasullo predicted that gas-processing revenues could decrease by as much as 50%.

A report by Bonner and Moore Management Science (1987), also assumed that a significant portion of the displaced normal butane would have to be marketed as fuel because alternative markets were already saturated.

The Bonner and Moore report was an update and modification to earlier work to account for reduced crude oil prices. The lowest price scenario was \$ 108 US/m^3 crude. Added cost estimates associated with restricting gasoline volatility were prepared for four regions in the U.S. Cost implications of consequent actions to the natural gas liquids industry were also bracketed. The four regions are mapped out in Figure VI-1.

Mathematical models of the composite refining capability were constructed for each region. Each refining model was required to meet 1990 demand forecasts using projected crude supplies. Three grades of gasoline were recognized: premium unleaded, regular unleaded and regular leaded (Tetra ethyl lead = 0.1 g/US gal). The models were run at current ASTM RVP limits and at three reduced levels of 10, 20 and 30 percent as laid out in Table VI-20. No credit was given to cases where gasoline was normally supplied at levels lower than suggested by ASTM D439.

EPA imposed assumptions that:

- methanol-plus-tertiary butyl alcohol should be used in 3% of all gasoline;

- ethanol should be blended into 7% of all gasoline.

Regional alcohol use was varied to reflect the same proportion of alcohol use in the past.

Additional cases were run for Region 3 such as:

- no investment (i.e., using existing facilities to meet reduced RVP);

- controlling gasohol RVP;

- butane market price effects;

- bunker sales volume effects.

Region 3 was also evaluated at three price levels of \$ 107 US/m^3, \$ 138 US/m^3 and \$ 170 US/m^3. The other regions were evaluated at the mid-point price.

Table VI-21 summarizes the cases studied by Bonner and Moore.

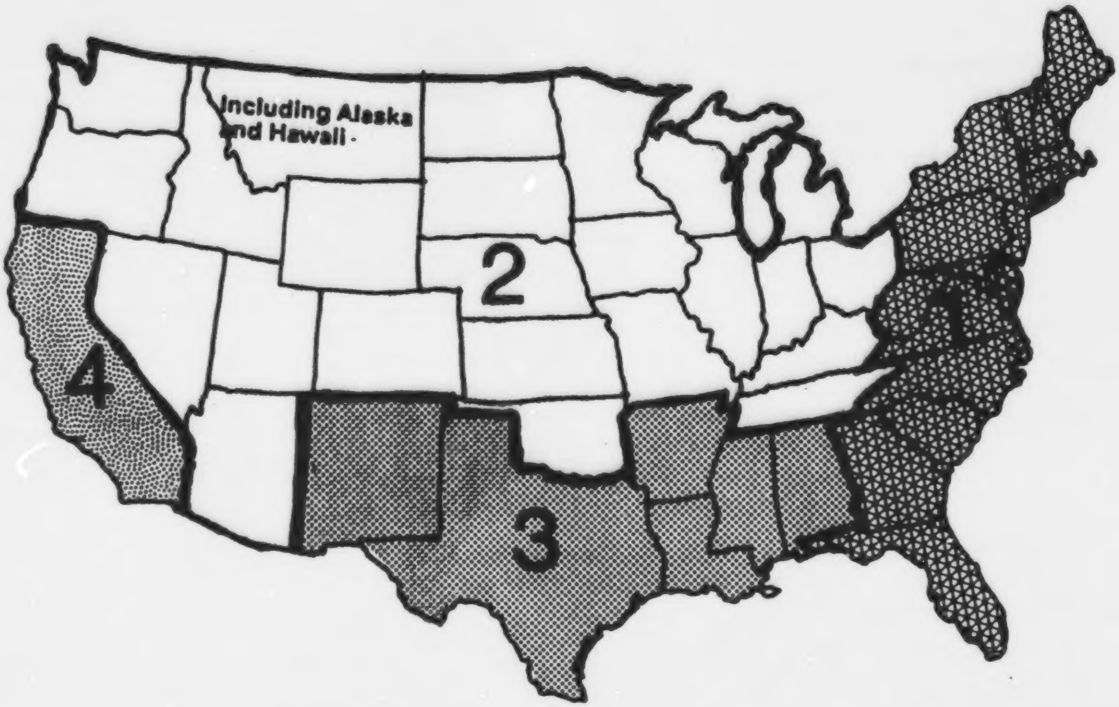
Including Alaska and Hawaii
1
2
3
4

FIGURE VI-1 REGIONS DEFINED FOR MODELLING REFINING OPERATIONS

Source: Bonner and Moore Management Science (1987)

TABLE VI-20 REGIONAL RVP CONTROL LEVELS

	SUMMER MAXIMUM RVP, kPa			
	BASES	1ST REDUCTION	2ND REDUCTION	3RD REDUCTION
Region 1	80.8	73.8	66.8	59.8
Region 2	75.7	69.1	62.5	56.0
Region 3	75.1	68.6	62.0	55.5
Region 4	63.5	58.0	52.5	46.9

Source: Bonner and Moore (1987)

TABLE VI-21 CASES STUDIED BY BONNER AND MOORE

	SUMMER REDUCTION				
	ANNUAL AVERAGE RVP	BASE RVP	FIRST	SECOND	THIRD
Crude @ \$ 107/m^3					
Region 3		X	X	X	X
Crude @ \$ 138/m^3					
Region 1	X	X	X	X	X
Region 2	X	X	X	X	X
Region 3	X	X	X	X	X
No investment			X	X	X
Ethanol w/control			X	X	X
Butane price variation				*	*
Increased bunker sales		X		X	
Region 4	X	X	X	X	X
Crude @ \$ 170/m^3					
Region 3		X	X	X	X

* RVP halfway between second and third levels

Source: Bonner and Moore (1987)

As part of their list of limitations of the study, Bonner and Moore emphasized that the results of the model were industry-wide and, therefore, do not reflect the extremes of individual refining situations. Other limitations included:

1. No changes in behavior of end-use consumers other than those included in demand forecast variations associated with varying crude costs were assumed.

2. Reduced evaporative losses and improved gas mileage effects were independent of region. Regions were also assumed to have the same car population compositions and summer driving habits.

3. The means of RVP control costs were not addressed (eg., an increase in gasoline pump price might prompt an increase in diesel-powered vehicles).

4. The capital investments for producing low volatility summer gasoline were amortized over that part of the year. No credit was given to the value of these facilities during the remainder of the year.

The results of the study are presented in Table VI-22. Note that only the direct refining costs affect society as a whole. The other costs result in savings to other sectors of society. The refining costs and added costs for control of RVP are also presented in Figure VI-2.

Figure VI-3 illustrates the impact of crude cost on RVP control costs. It is interesting to note that crude cost does not greatly affect RVP control cost. The lower demand forecasted at the higher crude price ($ 170 US/m^3) is responsible for the lower added cost of RVP control. Including natural gas liquids (NGL) costs spreads the control cost curves as seen in Figure VI-4.

An interesting finding shown in Figure VI-5 was that capital investment in process facilities reduces the refining cost by more than half. In other words, refiners should be notified well in advance of implementing RVP restrictions so that planning of new or expanded facilities can take place.

Regardless of the cases studied by Bonner and Moore, it is clear that the cost of RVP control can vary significantly from region to region. This was primarily due to the variation in refinery fuel cost.

Bonner and Moore indicated that the natural gas liquids industry was more strongly impacted by RVP controls. Table VI-23 lists the reduction in U.S. refinery purchases of n-butane. Note that most of the butanes are backed-out in the first two steps of RVP reduction.

TABLE VI-22 ESTIMATED COST IN US DOLLARS FOR CONTROLLING MAXIMUM RVP OF SUMMER GASOLINE (AVERAGE CRUDE COST OF $ 138/m^3)

		REDUCTION LEVEL				
		1st	2nd	1st+2nd	3rd	1st+2nd +3rd
Region 1						
Direct Refining Cost (*),	M$/D	11.0	83.6	94.6	164.6	259.1
Refining Income Loss,	M$/D	5.2	4.5	9.7	4.5	14.1
NGL - Industry Cost,	M$/D	18.7				
Subtotal Cost,	M$/D	34.9	88.1	122.9	169.1	292.0
Region 2						
Direct Refining Cost (*),	M$/D	173.4	491.3	664.7	675.0	1,339.6
Refining Income Loss,	M$/D	18.6	14.4	33.0	14.4	47.5
NGL - Industry Cost,	M$/D	167.2	119.7	286.9	2.1	289.0
Subtotal Cost,	M$/D	359.2	625.4	984.6	691.5	1,676.1
Region 3						
Direct Refining Cost (*),	M$/D	370.8	555.6	926.4	627.6	1,554.0
Refining Income Loss,	M$/D	24.9	18.6	43.6	18.5	62.1
NGL - Industry Cost,	M$/D	910.0	198.6	1,108.6	12.4	1,121.0
Subtotal Cost,	M$/D	1,305.7	772.8	2,078.6	658.5	2,737.1
Region 4						
Direct Refining Cost (*),	M$/D	32.1	123.0	155.1	177.6	332.6
Refining Income Loss,	M$/D	6.8	5.8	12.6	5.8	18.4
NGL - Industry Cost,	M$/D	0.0	0.0	0.0	0.0	0.0
Subtotal Cost,	M$/D	38.9	128.8	167.7	183.3	351.1
National Costs, M$/D						
Direct Refining Cost (*)		587.3	1,253.4	1,840.7	1,644.7	3,485.4
Refining Income Loss		55.5	43.4	98.9	43.3	142.1
NGL - Industry Cost		1,095.9	318.4	1,414.2	14.4	1,428.7
Total Cost,	M$/D	1,738.7	1,615.2	3,353.8	1,702.4	5,056.2
National Costs, MM$/Year						
Direct Refining Cost (*)		89.3	190.5	279.8	250.0	529.8
Refining Income Loss		8.4	6.6	15.0	6.6	21.6
NGL - Industry Cost		166.6	48.4	215.0	2.2	217.2
Subtotal Cost,	MM$/D	264.3	245.5	509.8	258.8	768.5

*	Societal Costs
NGL	Natural Gas Liquids
D	Days

Source: Bonner and Moore (1987)

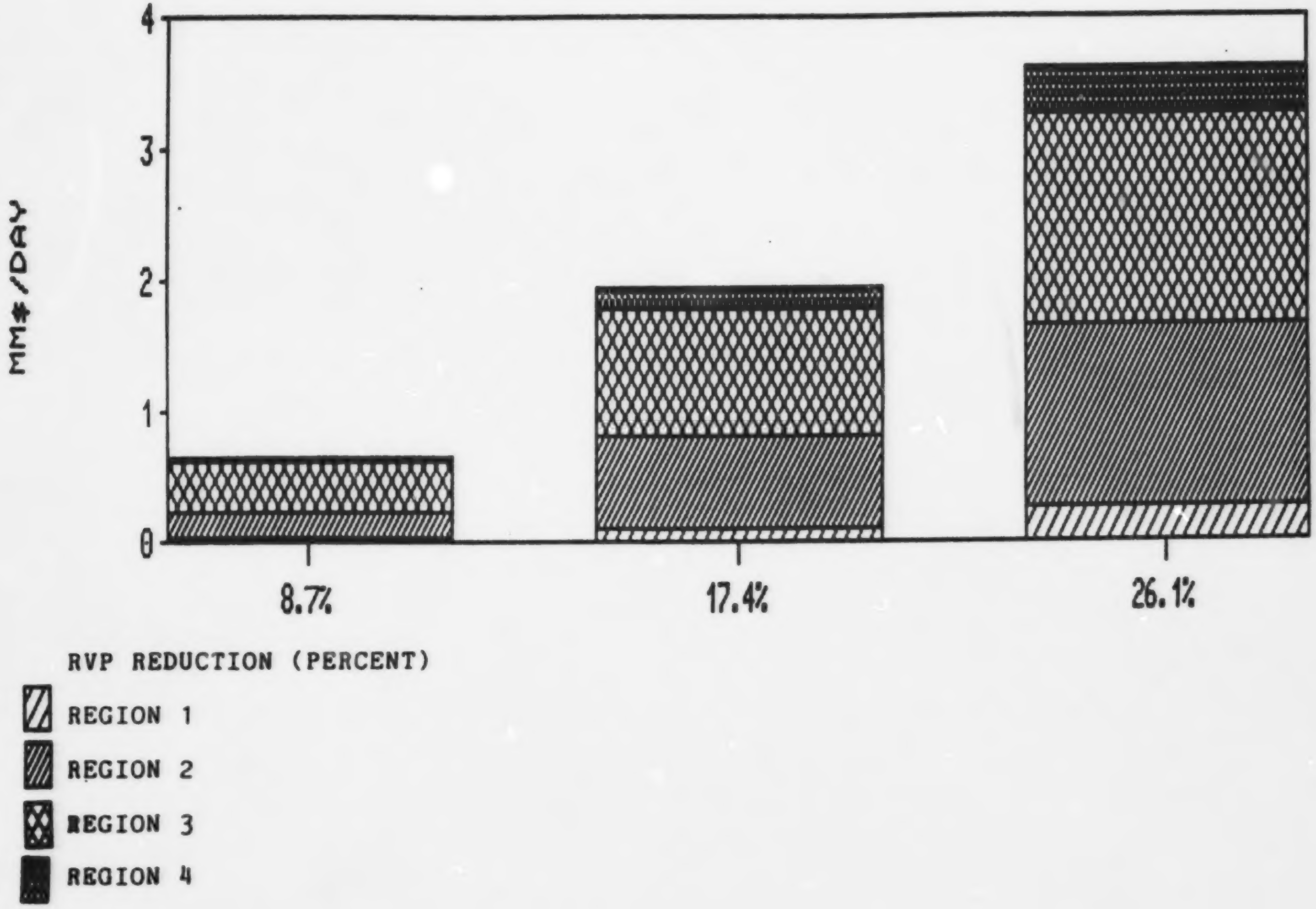

FIGURE VI-2 REFINING COSTS FOR CONTROL OF RVP IN SUMMER GASOLINE (CRUDE COST @ $ 138/m^3)

Source: Bonner and Moore (1987)

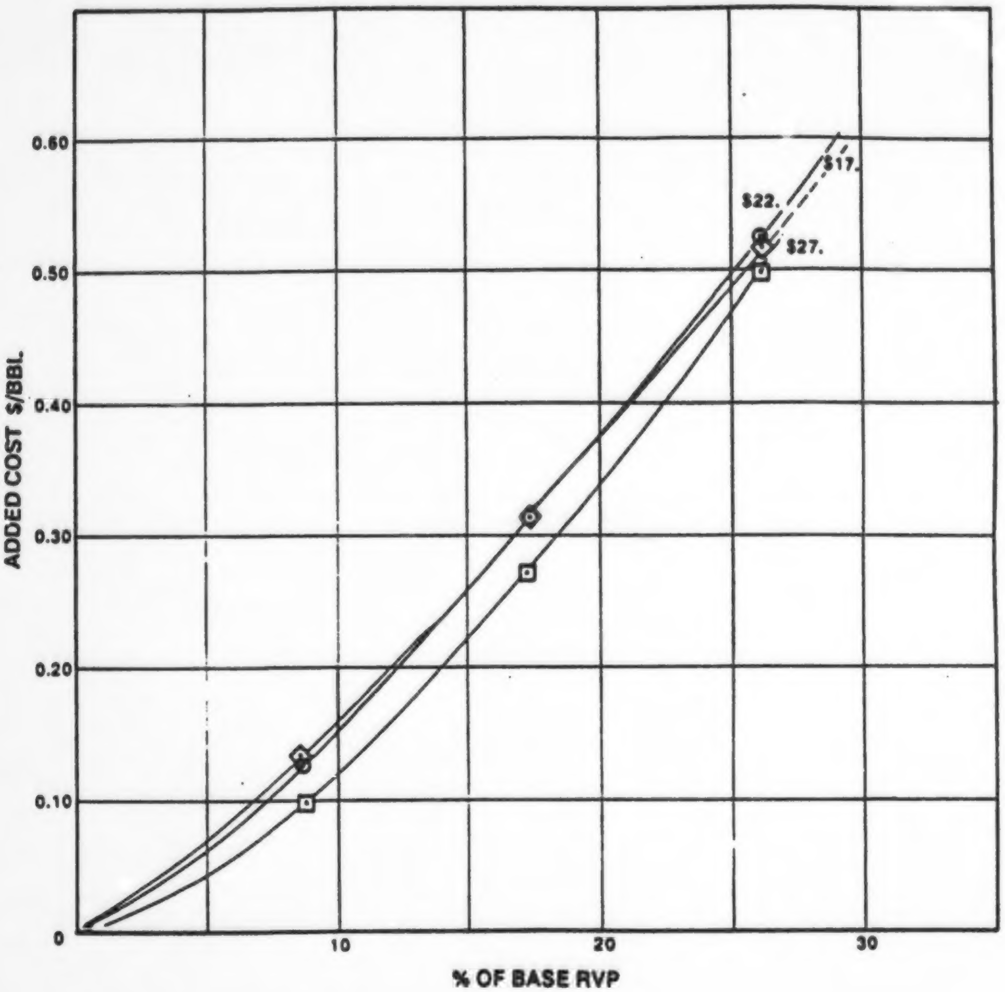

FIGURE VI-3 CRUDE COST EFFECT ON REFINING COSTS FOR RVP-CONTROL (REGION 3)

Source: Bonner and Moore (1987)

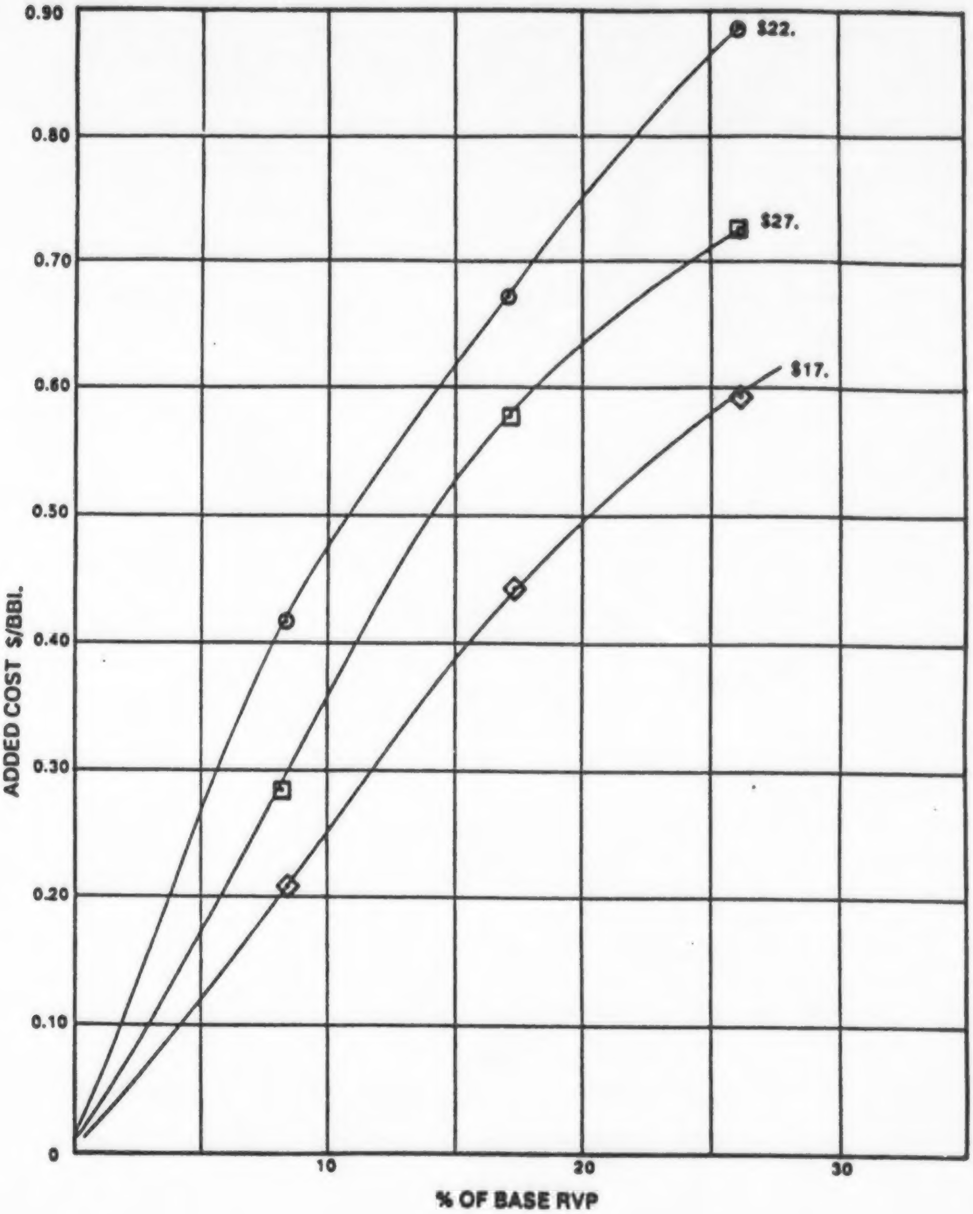

FIGURE VI-4 CRUDE COST EFFECT ON REFINING PLUS NGL COSTS FOR RVP-CONTROL (REGION 3)

Source: Bonner and Moore (1987)

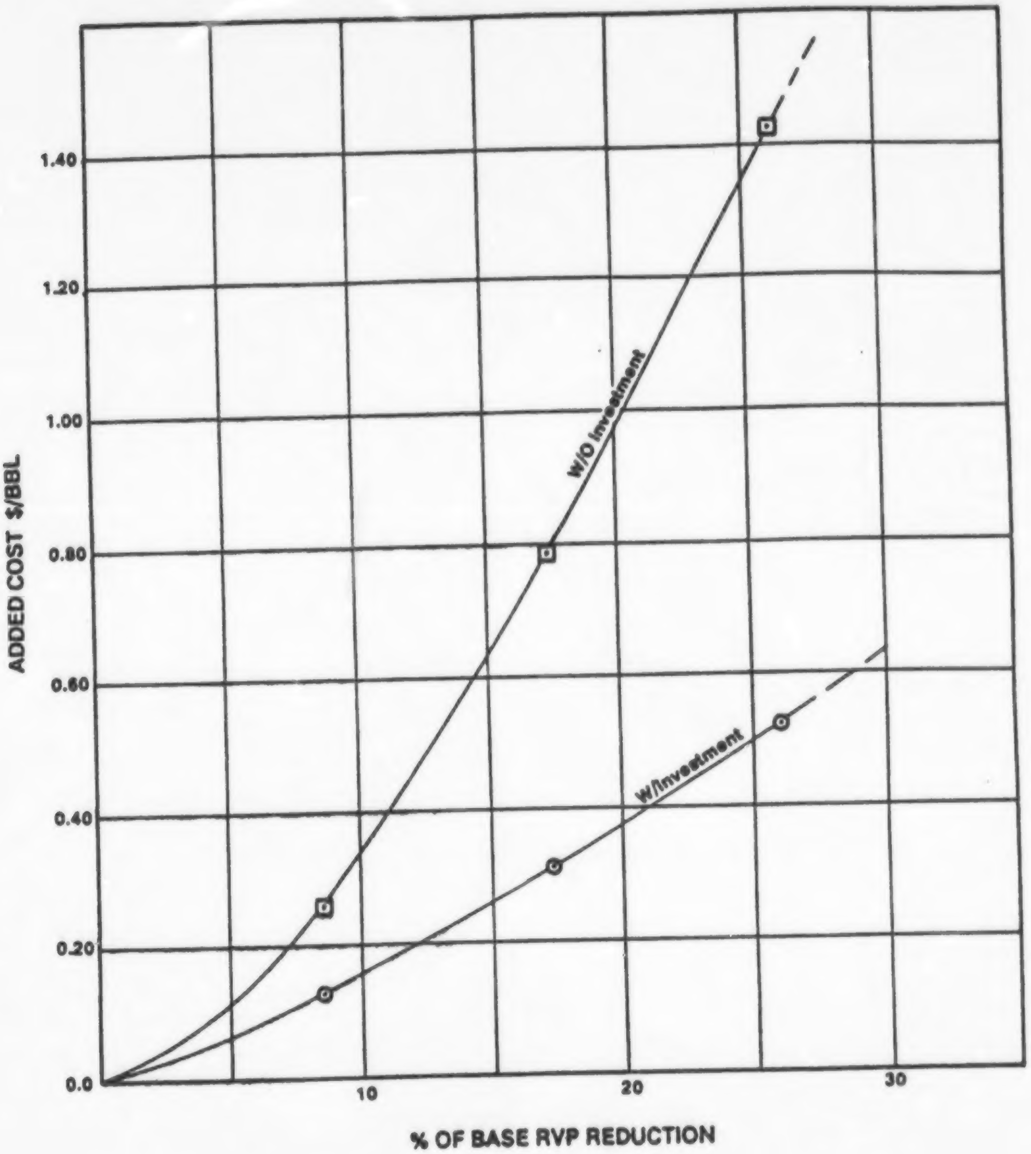

FIGURE VI-5 NO-INVESTMENT EFFECT ON RVP-CONTROL REFINING COSTS (REGION 3)

Source: Bonner and Moore (1987)

TABLE VI-23 REDUCTION IN U.S. REFINERY PURCHASES OF NORMAL-BUTANE (m^3/d)

RVP REDUCTION (% OF BASE RVP)	REDUCTION IN PURCHASES[1]
8.7	-19,000
17.4	-32,400
26.1	-32,700

[1] Reductions in refinery purchased relative to those for the summer base case with $ 138/m^3 crude cost

Source: Bonner and Moore (1987)

This is in contrast to Fasullo who forecast a continued backing out of butanes even to the third step of RVP reduction.

The State of Massachusetts will prohibit the sale of gasoline during the ozone season (May 1 to September 15) having RVP greater than 62 kPa (9 psi) beginning in 1989. VOC emissions are estimated to decrease by 22,700 tonnes/yr at a cost of \$ 4.00 (US)/m^3. This was based on a market comprised of eight states.

In the questionnaire study by Venturini et al (1975), industry responded with estimates of the cost to consumers of an RVP reduction from 62 to 41 kPa (9 to 6 psi). The estimates (probably based on individual cases) varied from \$ 0.50 US/m^3 to over \$ 8.00 (US)/m^3. The responses indicated up to three years of lead time was also necessary.

The industry also responded to the question of simultaneous lead and sulphur phase-outs. Most felt that together all three controls would require more severe refining, increase costs and/or reduce the availability of gasoline. Estimates of cost effectiveness of reducing gasoline volatility reported by respondents varied from \$ 0.92 to \$ 5.41 (US)/kg HC controlled (1975 dollars).

Stebar et al (1985) estimated the cost of reducing RVP at \$ 1.70 (US)/m^3 of gasoline and \$ 3.80 (US)/m^3 of gasoline for 7 and 15 kPa (1 and 2 psi) reductions respectively. Well over 75% of this cost was attributed to increased feedstock requirements. The bulk of the remainder was for capital requirements.

They also estimated cost effectiveness to be \$ 2.16 (US)/kg of HC controlled. When they accounted for an increase in fuel economy, the cost effectiveness was \$ 1.54 (US)/kg of HC controlled. These values were for a 10 kPa (1.5 psi) reduction from 72 kPa to 62 kPa (10.5 to 9.0 psi). This was in-line with US EPA and Motor Vehicle Manufacturers Association (MVMA) cost effectiveness estimates for Stage II and onboard controls. All of the values were in 1984 dollars.

An estimate by Texaco Inc., in Oil and Gas Journal (1988), put the cost of a 17 kPa (2.5 psi) RVP reduction from 79 kPa to 62 kPa (11.5 to 9 psi) at up to \$ 8.00 (US)/m^3 of gasoline.

Schleyer and Koehl (1986) who looked at vehicle refueling and evaporative emission control felt that RVP reductions were not as cost effective as onboard controls but were comparable to service station vehicle refueling vapour balancing. A 7 kPa (1 psi) reduction in RVP from 79 kPa to 72 kPa (11.5 to 10.5 psi) would cost \$ 352 (US)/tonne of HC. A 17 kPa (2.5 psi) reduction from 79 kPa to 62 kPa (11.5 to 9 psi) would cost \$ 704 (US)/tonne of HC, both assumed to be in 1985 or 1986 dollars.

Intille (1985) reported the additional annual refining cost of 7 and 15 kPa (1 and 2 psi) reductions at \$ 1.82 and \$ 4.27 (US)/m^3 of gasoline. About one-third of this cost was for raw materials. The remainder was because of higher operating costs. Furthermore, Intille added that the smaller, less complex refineries would be hit harder than the larger, more complex refineries. Some regions would also be more severely affected than others.

Cunningham et al (1987) compared an EPA and an API proposal for reducing RVP's. The EPA plan would require a 10 kPa (1.5 psi) and 21 kPa (3.1 psi) reduction from a base of 77 kPa (11.2 psi) over a six month refinery compliance period to go into effect in 1989 and 1992. The API alternative was for an 8 kPa (1.1 psi) reduction from a base of 74 kPa (10.8 psi) over a four month refinery compliance period to go into effect in 1988. The EPA alternative was reported to cost \$ 4.00 and \$ 9.00 (US)/m^3 of gasoline produced during the compliance period for the 1989 and 1992 proposals respectively. The API plan would cost \$ 2.00 (US)/m^3 of gasoline.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. The major VOC source categories for the study area, accounting for over 90% of the total VOC emissions, were:

   - storage of gasoline in fixed roof tanks > 150 m^3;
   - loading of trucks at bulk terminals;
   - loading of ships and barges at marine terminals;
   - service stations (collectively);
   - bulk users (collectively).

2. The 1985 emissions inventory was:

Total VOC's	6516.6 tonnes
Benzene[1]	18.9 tonnes
Toluene[1]	7.8 tonnes
Xylene[1]	1.3 tonnes

3. Proven technology for the control of VOC emissions could be applied to the following source categories, which account for almost 70% of the total VOC emissions in the study area:

   - storage of gasoline in fixed roof tanks > 150 m^3 by retrofitting the fixed roof tanks to internal floating roof tanks;
   - loading of trucks at bulk terminals by installing vapour collection and recovery equipment;
   - service stations by vapour balancing during deliveries and vehicle refueling;
   - bulk plants by vapour balancing fixed roof tanks during deliveries.

   Reductions of 3895 tonnes, almost 60% of the total VOC emissions from gasoline marketing in the study area could be realized by applying this proven technology.

4. The cost effectiveness of applying the control technology ranged from -$ 110/tonne of VOC to $ 4,000/tonne of VOC.

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[1] Based on speciation factors determined in this study.

5. The emission reduction and cost effectiveness of the various strategies are listed in order of cost effectiveness:

Fixed roof tanks	347.0 tonnes	$ -110/tonne
Truck terminals	1,051.2 tonnes	$ 80/tonne
Bulk plants	56.7 tonnes	$ 190/tonne
Service stations vapour balancing		
- during deliveries	1,420.8 tonnes	$ 340/tonne
- during vehicle refueling	1,056.6 tonnes	$ 4,000/tonne

6. The five scenarios evaluated are listed with cost effectiveness and combined emission reductions:

Scenario I	fixed roof tanks only	347.0 tonnes	$ -110/tonne
Scenario II	truck terminals only	1,051.2 tonnes	$ 80/tonne
Scenario III	Scenario II + service stations - delivery vapour balancing	2,446.2 tonnes	$ 170/tonne
Scenario IV	Scenario III + service stations - vehicle refueling vapour balancing	3,491.2 tonnes	$ 1,300/tonne
Scenario V	Scenario I + Scenario IV + bulk plants	3,894.9 tonnes	$ 1,200/tonne

7. Summertime gasoline volatility reductions would reduce emissions from gasoline marketing sources by less than 10% even when reduced to 62 kPa from levels of 72 - 86 kPa. This, of course, does not include reductions in emissions from motor vehicles that would result from using gasoline having a lower RVP. Literature reviewed in this study indicates that diurnal losses from vehicles is most sensitive to RVP reduction.

8. Emissions of aromatics can be reduced by the various control strategies as follows:

Fixed roof tanks	1.5 tonnes
Truck terminals (alone)	4.7 tonnes
Bulk plants	0.25 tonnes
Service stations vapour balancing	
- during deliveries	6.1 tonnes
- during vehicle refueling	4.6 tonnes

B. Recommendations

1. The speciation factors determined in this study are only an example for a typical "winter" gasoline vapour at about 12°C. More sampling and analysis is needed to determine the range of concentrations of the various species for all grades and brands of gasoline throughout the year and in particular "summer gasoline", and for emissions from the different types of sources that are present.

2. A detailed study is needed to determine the cost impacts of RVP reduction at refineries in Western Canada. A regional or, possibly, national perspective may be needed in this study to calculate costs of RVP reduction with confidence. This perspective is needed because of the national and international marketing of refinery products.

3. More information about the cost of retrofitting barges and ships for vapour balancing is needed before the cost effectiveness of vapour balancing at marine terminals can be estimated. The costs of the processing units and required piping are expected to be comparable to those for handling of vapours from truck loading.

4. More information about bulk users is required before any controls could be considered for this source. As a beginning, data should be obtained on the practises followed and the tankage present at major bulk users.

5. Industry with fixed roof tanks might wish to look at the economics of retrofitting the existing large fixed roof tanks to internal floating roofs.

6. The calculated cost effectiveness of VOC controls for sources in the gasoline marketing network should be compared to those for other sources of VOC emissions to establish optimal strategies for VOC reduction in the Lower Mainland. In the case of reduction of RVP, VOC emissions are reduced both in the gasoline marketing network and for the gasoline end-users, resulting in

reduction in VOC emissions significantly greater than for the gasoline marketing network alone.

7. If a decision is made to implement controls for sources in the gasoline network, then the controls discussed in this study should be applied to the following sources, in order:

    - fixed roof tanks > 150 m^3;
    - truck loading terminals;
    - bulk plants (vapour balance for fuel deliveries);
    - service stations - Stage I (vapour balance for fuel deliveries);
    - service stations - Stage II (vapour balance for vehicle refueling);
    - barges and ships.

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